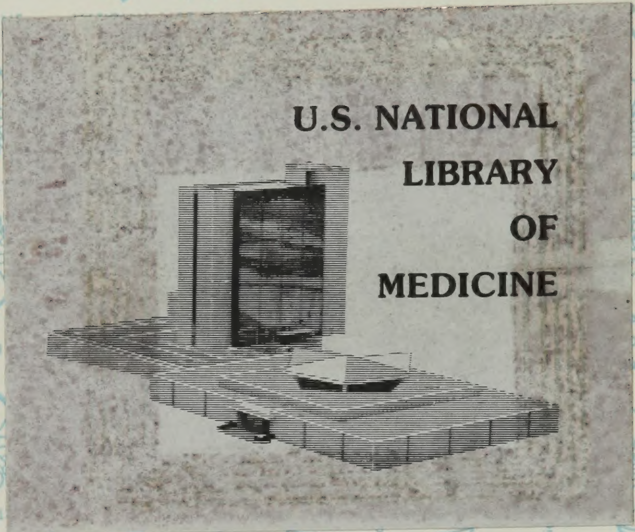
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The MEDICAL DEPARTMENT OF THE UNITED STATES ARMY IN THE WORLD WAR

VOLUME XI

SURGERY

PART ONE

GENERAL SURGERY
ORTHOPEDIC SURGERY
NEUROSURGERY

PREPARED UNDER THE DIRECTION OF

MAJ. GEN. M. W. IRELAND

The Surgeon General

WASHINGTON : : GOVERNMENT PRINTING OFFICE : : 1927

LETTER OF TRANSMISSION

I have the honor to submit herewith a portion of the history of THE MEDICAL DEPARTMENT OF THE UNITED STATES ARMY IN THE WORLD WAR. The portion submitted is Part One of Volume XI, on the subject of SURGERY, and includes General Surgery, Orthopedic Surgery, and Neurosurgery.

M. W. IRELAND,
Major General, the Surgeon General.

The SECRETARY OF WAR.

[a] The highest rank held during the World War has been used in the case of each officer.

PREFACE [a]

This part of Volume XI, Surgery, comprises three sections, devoted to general surgery, orthopedic surgery, and neurosurgery. This grouping of subjects is inevitable, since some changes in the original plan (which was to narrate in separate volumes general surgical activities and the surgical activities relating to injuries of the brain, spinal cord, and peripheral nerves) were necessitated by the fact that the anticipated quantity of manuscript on these subjects did not prove adequate for more than one book (part of a volume). Furthermore, though it was intended to have the subject of roentgenology in a separate volume, a chapter only has been given to it, and this appears in the section on general surgery herein.

The statistical data in the section on general surgery, particularly those concerning the incidence of various kinds of battle injuries, are essentially general in character; that is to say, they are studies, made in the home territory and after the war, of records received from all sources. Though these data serve a very useful purpose, a far better purpose would have been served had studies been made along this line on special types of injuries in the theater of operations and by trained observers. Such a course of procedure was impracticable, however, in view of the fact that our available personnel was relatively very limited at the time when we were receiving in our hospitals in France the major portion of our wounded. Furthermore, it must be borne in mind that most of our battle casualties resulted from two military operations—the St. Mihiel operation and the Meuse-Argonne operation. The former began on September 12, 1918, and the latter ended on November 11, 1918. Thus it will be seen that relatively little time was available for other than the reception and care of the wounded.

Much of the material of some of the chapters of the general surgery section was obtained from published sources and used as a basis for the chapters as they now stand. For the use of this material grateful acknowledgment is now made to Oxford University Press, American Branch, for permission to use such text and illustrations as were found to be desirable in the chapters on "Localization and extraction of foreign bodies under X-ray control"; "Wounds of the soft parts and wounds of the joints"; "Wounds of the chest"; "Wounds of the abdomen." Acknowledgment is also made to Paul B. Hoeber (Inc.), for permission to use certain parts of the United States Army X-ray Manual for the chapter on "Localization and extraction of foreign bodies under X-ray control."

Grateful acknowledgment is made to the Bureau of Medicine and Surgery, Navy Department, for certain plates of the Report on the Medico-Military

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[a] For the purpose of the History of the Medical Department of the United States Army in the World War, the period of war activities extends from April 6, 1917, to December 31, 1919. In the professional volumes, however, in which are recorded the medical and surgical aspects of the conflict as applied to the actual care of the sick and wounded, this period is extended, in some instances, to the time of the completion of the history of the given service. In this way only can the results be followed to their logical conclusion.

Aspects of the European War, by Surg. A. M. Fauntleroy, United States Navy, 1915, which are used partly to illustrate Chapter II of the first section of this volume.

The section on orthopedic surgery is so arranged as to show, first the character of treatment it was possible to give to the injured assigned to the care of orthopedic surgeons in the American Expeditionary Forces, and, second, the after care of such cases in the home territory. The section was compiled from the contributions of various officers of the orthopedic division whose names are as follows: Col. Elliott G. Brackett, M. C.; Col. Joel E. Goldthwait, M. C.; Col. Nathaniel Allison, M. C.; Lieut. Col. Clarence B. Francisco, M. C.; Lieut. Col. George W. Hawley, M. C.; Lieut. Col. Hiram W. Orr, M. C.; Lieut. Col. Robert B. Osgood, M. C.; Lieut. Col. James T. Rugh, M. C.; Lieut. Col. David Silver, M. C.; Maj. Zabdiel B. Adams, M. C.; Maj. Wallace Cole, M. C.; Maj. Murray S. Danforth, M. C.; Maj. Norman T. Kirk, M. C.; Maj. John L. Porter, M. C.; Maj. Edward A. Rich, M. C.; Maj. Philip O. Wilson, M. C.; Maj. Carl C. Yount, M. C.; Capt. Horace Morison, San. C.; Capt. John H. Morse, San. C.

Col. Elliott G. Brackett, M. C., who edited the section on orthopedic surgery, was chief of the division of orthopedic surgery, Surgeon General's Office, during the war.

The section on neurosurgery was edited by Lieut. Col. Charles H. Frazier, M. C. Shortly after the war began, Colonel Frazier was placed in charge of the Army neurosurgical school of instruction, which was established in Philadelphia at that time. When General Hospital No. 11, Cape May, N. J., was instituted, Colonel Frazier became its chief of neurosurgical service. Here he remained for the greater part of the war period. General Hospital No. 11 was one of the special hospitals designated to receive from overseas, cases of peripheral nerve injuries, and wounds or injuries of the skull or brain and spinal cord. Subsequent to his service at this general hospital, Colonel Frazier was on duty in the subdivision of surgery of the head, Surgeon General's Office, and became a member of the peripheral nerve commission, appointed by the Surgeon General on January 29, 1919.

It was upon the advice of the peripheral nerve commission that the peripheral nerve register was distributed with the view of recording thereon the results of the examination of every peripheral nerve case. Since duplicate peripheral nerve registers of the cases examined were furnished the Surgeon General's Office, the hope was entertained that uniform data of a large number of cases of peripheral nerve injuries might lead to a determination of the end results of such cases. However, with the wide dispersion of these cases throughout the country, following their discharge from military hospitals, it would have been necessary, in the subsequent reexamination of them, to rely upon medical men inexpert in neurological examinations. In consequence, efforts to determine the end results necessarily were abandoned.

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INTRODUCTION

Considering the volume of surgery done during the World War, and the mass of literature resulting from surgical experiences in that war the natural inference is, the developments were many. Each war of magnitude in the recent past, certainly within the period of modern surgery, has advanced to a greater or less degree the boundaries of our knowledge of military surgery; this, in turn, obviously has reacted beneficially on the practice of surgery in general.

To determine how extensively the experiences of the surgeons of the World War have influenced the development of surgery, one must first know what, with the knowledge at hand, it was hoped to accomplish with surgery during that war. The practice of military surgery is inevitably circumscribed. Disregarding its primary purpose—that is, the conservation of combat troops—its scientific purpose is to preserve life, to prevent deformity, and to reconstruct physically. Since in the preservation of the life of the wounded the surgeon has been most concerned with preventing or combating wound infection, it is of present interest to determine not only how successful he was in this direction during the World War, but also to trace briefly the steps which permitted the establishment of the modern principles of surgery along this line. It must be borne in mind also that changes which have been effected in the general treatment of gunshot wounds necessarily have followed changes in armament.

Modern surgery had its beginnings in the sixteenth century, when Paré, no longer in the possession of the hitherto used cauterizing oils, hesitatingly made use of innocuous wound drainings, discovering, thereupon, not only that gunshot wounds were not poisonous in the sense previously held, but also that their healing was dependent upon the body itself. The period from Paré's time to our Civil War witnessed great strides in the technique of operative surgery, thus enabling it to become firmly established as a science; however, little or no improvement was made in respect to the general treatment of wounds. Except in so far as the greater array of surgical instruments and the variety of operations performed are concerned, a perusal of experiences of methods of general wound treatment during Civil War days might just as well apply to the sixteenth century. The inevitable pus of a wound was just as "laudable;" exploring fingers just as dirty. Keen, in comparing old and new war surgery, has this to say concerning his Civil War experiences:

> Our dressings in the sixties consisted of simple ointments, often only cold unboiled water followed later by constant poulticing to initiate and promote the abundant flow of pus., Little did we dream that our patients recovered as a result of a kind *vis medicatrix naturæ*, and, as we now know, in spite of our encouragement of infection.
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> * * * * * * *
>
> We used only the ordinary marine or toilet sponges. After an operation they were washed in ordinary water to cleanse them of blood and pus, and were used in subsequent operations. In our ignorance of bacteriology we did not know that they harbored multitudes of germs which infected every wound in which they were used. If one fell on the floor it was squeezed two or three times in ordinary water and used at once!

The amazing advances of modern surgery were made possible by the teachings of Lister, which first appeared in printed form only two years after the cessation of our Civil War. Hitherto, unless a wound healed by primary intention, it was considered natural for it to go through the stages of granulation and suppuration. Since the stage of suppuration followed that of inflammation, during which there were the usual signs, including the "surgical fever," and was remarked as representing a relief of the fever, it was looked for as a desirable effect; hence the poultices.

The Franco-German war of 1870–71 was the first war to occur after the beginning of the period of Listerism. At this time, however, antiseptic methods of wound treatment were but little known to many surgeons; they were also quite complicated and especially difficult of application in war time. The French in this war made no use of the new methods; the Germans attempted it and had some satisfactory results. Between this time and the occurrence of the Russo-Turkish War of 1877, greater opportunity had been afforded surgeons in general to try out Listerism and to be convinced of its merits, and in the war of 1877 we find successful though very limited efforts being made to combat surgical infection based on an intelligent conception of its real cause.

In the application of this knowledge in the general treatment of gunshot wounds in the Russo-Turkish War, the surgeons at the front were given thoroughly to understand that there was to be only one line of treatment—to occlude the wound, to lay the wounded part in a suitable position on the litter, and to render it immovable; in other words, to practice conservatism.

Coincident with these strides in the science of surgery, tacticians also were improving armament. In 1866, our slow-firing muzzle-loading rifle became a breechloader. Subsequently, between this date and 1892, improvements were made in the rifle by increasing not only the rapidity of fire but also the effective range. Other advances of the period, seemingly entirely remote from armament, had a great influence on the startling improvements in armament soon to be made. Means of locomotion made it possible more rapidly to concentrate large numbers of troops at weak points. Thus if a greater rapidity of rifle fire were effected than was afforded by the single-firing breechloader of 1866, this with more rapid means of concentrating troops might afford a superiority of rifle fire even to inferior numbers. So, with this in mind the magazine breechloader was devised, and adopted by the great military nations. Our first magazine rifle of reduced caliber was adopted in 1892 under the name of the Krag-Jorgensen, after its two Norwegian inventors. This is the type of rifle with which the opposing forces were armed in the next two wars—Spanish-American (1898) and South African (1899–1901). We now possessed what was generally looked upon as a humane military weapon, whose conoidal, jacketed missile when fired into soft tissue caused considerably less contusion and laceration than was true of the older rifle balls; and since there was less devitalization of the tissue surrounding the wound tract, the wound had the appearance of being clean cut, and proved in most cases to be relatively sterile. A suitable first-aid dressing, applied to such an injury on the field and shortly after its inception, effectively occluded it.

First-aid dressings for wounds were used by the British as early as the Crimean War. Since this war occurred prior to the period of Listerism, these dressings made no pretense of accomplishing anything but the prevention of a gross soiling of the wound; they consisted merely of a calico bandage and four pins carried in the soldier's knapsack. It was not until the Sudan campaign of 1884 that a dressing of surgical utility was used by the British. This dressing was made of two pads of carbolized tow, a gauze bandage, pins, and a triangular bandage, all sealed in tin foil covered by parchment. In 1889, cognizance by us was taken of the desirability of having first-aid packets available for front-line dressings, but it was not until 1892 that they were officially adopted. It is interesting to note here the difference in the present meanings of the words aseptic and antiseptic as applied to the treatment of wounds and that which obtained in the latter eighties. The following extract is taken from Smart's Handbook for our Hospital Corps, published in 1889:

> The object of *aseptic* treatment is to destroy germs that are present in a wound, and thereafter to effect their exclusion from its tissues. The object of *antiseptic* treatment is neither to kill nor exclude, but to suspend their vitality, and prevent fermentative changes.

In 1892, as mentioned above, our Army adopted a first-aid packet comprising two compresses of antiseptic gauze, each wrapped in a piece of waxed paper; an antiseptic roller bandage; a triangular bandage; and two safety pins. In 1896 it was required that each officer and enlisted man of the Army have one of these first-aid packets as a part of his equipment.

Thus when the Spanish-American War began our military surgeons were in the possession of adequate knowledge as to the reasons for the occurrence of infection in gunshot wounds, and means for its mitigation, if not prevention. Experiences in the Spanish-American and South African Wars with wounds that were produced by the small-caliber, steel-jacketed missile and that were treated by the sublimated first-aid packet, showed that the vast majority of them healed by primary intention, thus giving rise to a sense of security as to the treatment of such wounds that was to be thoroughly shaken in the World War.

In both the Spanish-American and South African Wars, injuries caused by the rifle far predominated over those caused by artillery, as had been true of previous wars. This was so to such an extent that in treatises concerning gunshot wounds of these two wars, shell wounds received relatively scant notice since they possessed small surgical interest. It may be noted, however, that they invariably were infected.

Between the two wars just referred to and the World War two things occurred which should have set military surgeons thinking. These were change in the character of the rifle missile and a progressively greater tendency to make use of artillery. Tacticians, ever seeking for a lengthening of the range and an increased accuracy of fire, had in the period in question decreased the weight of the missile and made it pointed instead of ogival, with the view of having it offer less resistance to the air. Its center of gravity being now well back toward its base did away with its former stability when striking structures of even slight resistance; that is to say, resistance offered by such parts of the body as the chest and abdominal walls causes the bullet to turn on its short axis, thus resulting in wounds comparable to those inflicted by an exploding

bullet. With the attendant destruction of tissue, it is easy to see that in such wounds the aseptic and conservative surgery of the beginning of the twentieth century would be totally inadequate. As to the progressive increase in the use of artillery during the period of aseptic surgery: In the Spanish-American and South African Wars shell and shrapnel wounds were between 5 and 10 per cent of the total gunshot wounds. In the Russo-Japanese War (1904–5) Lynch reported that in the Japanese First Army, engaged in field operations alone, shell wounds were 14 per cent. In the Turko-Balkan War (1912–13) shell and shrapnel wounds averaged about one-third of the whole. It is not the present purpose to give detailed consideration to statistical matter concerning the World War, but the fact remains that, though one would necessarily expect an increase in the proportion of shell wounds in siege warfare—the greater part of the duration of the European war 1914–1918 may be likened to siege warfare—no one evidently was prepared for the preponderant use of heavy projectiles in that war. Thus the ratio of gunshot wounds formerly obtaining, in which the wounds caused by rifle missiles were typical, became reversed and so found surgeons in a state of unpreparedness.

Considering military surgery as a special branch of the science of surgery necessitates a few interpolative words here as to the evolution of the military surgeon himself. To revert to the fifteenth century, it is an incontrovertible fact that the importance of the surgeon to armies then was recognized as being great. Reference already has been made to the work of Paré in this connection, making him an outstanding figure. The poetry of war surgery was again written by the French in the days of Napoleon I when Percy, and especially Larrey, were competent surgeons, as well as exceptionally competent administrative medical officers. Straub mentions, however, that this combination worked badly in our Civil War, as our doctors, unacquainted with war as they were, were all too prone, when charged with important administrative duties such as those of a division surgeon, to devote their energies exclusively to amputations rather than to exercise the supervision essential to their positions. This was all before the dawn of modern sanitation, and for centuries it was the surgeon who held the proscenium in the medicomilitary theater. In our earliest history as a nation the claims of surgery were not overlooked, for we had in the Revolutionary War a surgeon general as well as a physician general. Why the title "surgeon general" persisted is unknown. Perhaps because at that time the importance of surgery was recognized as paramount. Custom and not practice seems later to have dictated the title "military surgeon." As late as our Civil War, however, the surgeon still remained the important medical officer, though now some very competent medicomilitary administrators came to the fore. A change seems to have taken place in the medicomilitary hierarchy at a later period. With our next war—the Spanish-American—and the subsequent long military occupation of the Tropics, surgery from the military standpoint sank into insignificance and the thoughts in sanitation overshadowed everything else with our Army Medical Department. Nor did our small Regular Army afford much opportunity for specialization in surgery. Some good surgeons have developed therein, but this was not by virtue of but despite the system in vogue. The situation was quite otherwise

in our civilian medical profession, in which knowledge of surgery had advanced by leaps and bounds since the beginning of the antiseptic and finally the aseptic eras; operations which would have been truly marvelous to the Army surgeons of preantiseptic days were a matter of everyday occurrence now. These wonderful strides had resulted in a high degree of specialization which had to be taken into consideration in the plans of the Army to use most effectively civilian surgeons. But in this no great difficulty was encountered, since it was the general policy of the Government to secure the best talent available in all lines of activity for the care and welfare of the Army to be used in the World War, and committees representative of the many specialities of surgery as well as medicine were appointed by the general medical board of the Council of National Defense. Such committees were composed of the leaders in their respective specialties as well as representatives of the Medical Department, and soon after their organization many were gradually absorbed by the Medical Department, thus permitting them to continue as working components of our military machine. A plan was therefore perfected which enabled American surgeons to work in the Army along the lines of their civil experience, and there came into being the general surgeon, the orthopedic surgeon, and the neurosurgeon.

It is needless to say that the majority of our civil surgeons, regardless of their qualifications, were needful of adaptation to the practice of military surgery, encompassed, as it inevitably is, by the stress of circumstances, the very masses of material with which it is necessary to deal, and, in the advanced hospitals of the theater of operations, the practical impossibility of securing surgical cleanliness.

Fortunately, when we entered the World War, we could take advantage of the several years of experiences of our surgical confrères in the allied armies and thus eliminate some of the mistakes which had been made by them. As explained above, prior to the outbreak of the war of 1914–1918, military surgeons still considered the relatively clean wound made by the rifle missile the typical gunshot wound, and that its treatment would consist largely in the early application of a first-aid dressing, plus some means of prophylactically antisepticizing the wound. With this thought in mind the first-aid dressing itself had been for some years prepared in a subliminated form, but a further step had been taken following the discovery of the high antiseptic value of tincture of iodine when applied to the skin and to ordinary wounds. Unfortunately, as has been made clear above, the new, pointed missile of the rifle frequently caused a wound whose tract was surrounded with devitalized tissue; also, there was now a preponderance of wounds caused by artillery missiles. Consequently, surgeons in the early part of the war were confronted with an overwhelming amount of wound infection; and since in the years immediately preceding the war prophylactic antisepticizing as a method had become so strongly entrenched among them, it was but natural that their efforts to treat the infected wounds should be directed toward securing efficacious antiseptics. In so far as the prophylactic antisepticizing of wounds in front areas was concerned, all efforts in this direction proved futile, because of the presence of

the damaged tissue in which the infecting organisms could readily propagate and where they were inaccessible to antiseptics.

Surgeons now resorted to débridement, a practice in vogue centuries ago, consisting of opening up the wound so as to rid it of the foreign contained matter and the products of inflammation, the destroyed tissues being left to a natural process of elimination. This practice, and in conjunction with it, was followed by the use of such substances as the hypochlorites to dissolve the destroyed tissues, and, later, the actual excision of all devitalized tissue. Thus leaving only well-nourished tissues, which of themselves could overcome infection, made it possible now to close the wound either by primary or delayed primary suture. To this practice the name débridement clung, though, as pointed out, it was a radically different procedure.

The excision of gunshot wounds was a firmly established practice by the time we had any great number of wounded in our hospitals in France, so that we now had available to us a means which not only materially reduced the mortality of gunshot wounds but also materially reduced the average length of stay of the injured in hospital because of their wounds.

The applicability to civil surgery of this sound method of treating wounds is measurably slight, perforce, nevertheless it has its field, particularly in industrial surgery; therefore, it represents a distinct contribution on the part of military surgery.

Other advances, such as the treatment of shock, the handling of fractures, and the control of tetanus, will not be touched upon here, since to do so would be but anticipating what is given fully in the following parts of this volume.

It was the policy of our Government to furnish the Army with the very best in the way of surgical personnel and to afford this personnel the opportunity to function best, by making available working facilities. Furthermore, the treatment of the wounded was not to be considered complete, in so far as our Medical Department was concerned, until after the wounded had attained complete recovery, or as complete as it could be, considering the nature of their respective disabilities.

SECTION I

GENERAL SURGERY

CHAPTER I

HELMETS AND BODY ARMOR—THE MEDICAL VIEWPOINT [a]

The nature of a projectile determines in no little degree the character and treatment of a wound. Bullets or fragments of shell of high velocity are less serious sources of infection than those of low velocity. A ball which mushrooms is eminently destructive—to such a degree, indeed, that bullets designed to mushroom have been forbidden in warfare. It follows that a breastplate of metal which tends to mushroom any impinging ball (fig. 1)

FIG. 1.—Mushrooming of bullets upon impact with armor. The missile on the left is a copper-jacketed bullet of 230 grains; the one in the middle is a similar missile deformed upon contact with armor at a velocity of 800 foot-seconds; the remaining missile is a similar one mushroomed upon impact with armor at about 1,500 foot-seconds

would be justly regarded as a source of considerable bodily danger to its wearer. Hence, from the general viewpoint, the use of armor would be sanctioned only when, on broad averages, the soldiers who wear it would be able to take a more effective part in warfare. In a word, any army could afford to lose one soldier, if by means of armor two soldiers were able to remain in active service.

To discuss the nature of wounds produced by projectiles which had pierced a helmet or body defense is not the purpose of the present chapter; their nature and fate is considered in Chapter II of this volume. It is rather to show the findings of departments of war of various countries as to the use of armor as a practical means of saving "effectives". It has been shown [a] that: (1) Helmets and body armor were found, on broad averages, of distinct advantage to the wearers. (2) A steel helmet became part of the regular military equipment of many nations; at the front its use was obligatory. (3) Body armor

[a] The statements of fact appearing herein are based on "Helmets and Body Armor in Modern Warfare," by Bashford Dean, Ph. D., New Haven, Yale University Press, 1920.

was used only for special service, e. g., for bombing parties, or for machine gunners. (4) Its employment was limited partly or largely by the inconvenience which its weight caused its wearers, who on the first opportunity, disregarding the protection it afforded, were apt to throw it aside.

Experiments to determine the protective qualities of helmets were first carried out by the Intendant General Adrian (1914–15) of the French Bureau of Inventions, whose faith in his work led to the arming of soldiers in great numbers with the newly devised defense, half a million helmets having been placed in the field in the initial experiments. Had these been carried out on small groups, as an economical measure, a true result might not have been forthcoming, for it will be seen (1) that an innovation of this kind would have been resisted firmly by already overequipped soldiers, whose neighbors were not thus additionally burdened, and (2) that the results of a small experiment would have failed to impress experts, medical and technical—who regarded the use of armor as "dead as Queen Anne." In fact, shortly after the experiment of General Adrian, many critical reports were filed showing that hospitals were crowded with head-wound casualties in helmet-wearing soldiers. It was only the more careful analysis of the data which showed that these men, although wounded, were men who were saved, for without their helmets most of them would have succumbed to cranial injuries.

Effort was made by the writer to tabulate the practical results in the use of the helmet on different fronts, but no detailed statistics were to be had. Hospitals were usually crowded with cases, and their personnel could give little time or effort to determining the cause and the condition of the wounding. Of the French, however, the hospital records show that in 1915 (before the introduction of helmets) about one head wound in four proved fatal. After the introduction of the helmet, however, statistics in the same hospitals show that in head wounds, at the worst, but one case in four and a half proved fatal, and at the best one case in seven—a perceptible betterment of conditions. Evidence is abundant which shows that the same shrapnel helmet saved its wearer many times. In any event, the results in this direction were convincing—the shrapnel helmet had come to stay.

HELMETS OF VARIOUS NATIONS

The merits, from the medical viewpoint, of three types of helmets may be considered: (1) The French, adopted also by Belgians, Italians, and Slavs. (2) The British, which was adopted also, but provisionally, by the American Army. (3) The helmet of the Central Allies.

The French helmet was a response to the need of producing quickly a metal head defense which would be reasonably strong and not so heavy as to cause serious discomfort to its wearer. It weighed 27 ounces, was manufactured of a mild steel with medium resistance and was built up; the parts often were separated by the shock of the projectile. Impact tests [a] demonstrated that the French helmet was perforated at a point pressure of from 674 to 756 pounds, indenting to a depth of from one-fourth to one-fifth inch. Such metal was easily penetrated by the Browning revolver of .25 caliber at a

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[a] Conducted by Dr. E. Dupuy, of the Chemical Laboratory of the Sorbonne.

6-foot distance, the ball then penetrating "hardwood" behind it to a depth of from 3½ to 5½ inches. The French helmet is therefore weak; it has, in fact, but half the strength of the British helmet. The wonder is only that the French helmet proved so great a success; it demonstrated, at least, that the soldier of 1915 was subject to injury from splintered missiles of low velocity, spent shrapnel, and the like.

The British helmet, weighing 35 ounces, made practically of a single piece of 12 per cent manganese alloy, ruptured only, according to Dupuy's results, after a blow equivalent to 1,580 pounds had been given, the rupture following a point indentation of 0.28 inch—an indentation not extreme when it is recalled that the French helmet indented to 0.25 inch at half the pressure. The American helmet, of similar model, was slightly heavier than the British, averaging about 1 ounce. It was made of a somewhat different manganese alloy, and was on the average from 12 to 15 per cent stronger (Dean's experiments). An improved steel (manganese-nickel alloy of Baker) produced a helmet with the same resistance to rupture as the German one at a saving of from 4 to 9 ounces in weight. Improvement in steel alloy which could be pressed into helmets was here noteworthy.

The German helmet, weighing from 40 to 48 ounces, was admirably pressed in a silicon nickel steel; it was about 30 per cent stronger than the English helmet, but its greater weight was a distinct disadvantage.

From the medical viewpoint, the matter of the form of a helmet proved of considerable moment. Strong recommendations were made that an American helmet should be introduced which would cover in greater degree the back of the cranium, its sides and base. For it was clear that the British helmet was seated too high up on the head. Its brim, it is true, was a strong defense from missiles approaching from above, but it was of no value as a protection from splinters or shrapnel from lower levels. The form of the helmet finally recommended to the American Army is shown in Figure 2. This protected in best degree the region of collected nerve fibers, the thinner part of the cranial wall, and proximal cranial nerves.

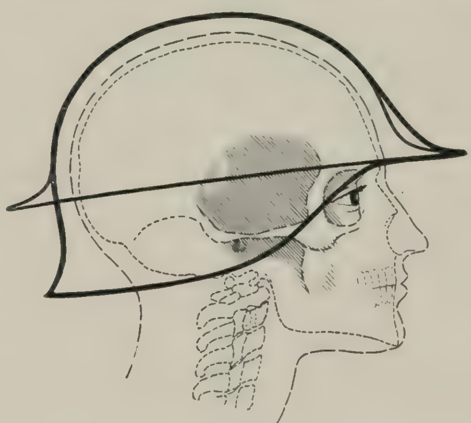

FIG. 2.—Diagram showing larger degree of protection of American helmet, Model 2A, contrasted with standard British model (less heavy line), the thinner cranial wall indicated by shading. The new model protects the sides and base of the cranium

THE FREQUENCY OF INJURY FROM MISSILES OF LOW VELOCITY, WITH RESPECT TO THE WEARING OF ARMOR

The statistics of European hospitals compiled through the year 1916 (later figures not accessible) demonstrate that three-quarters of the casualties were due to missiles of low velocity—roundly, those traveling at a rate of less than a thousand feet per second—to which the lightest type of helmets and

armor used in the World War would have been proof.[a] And from French statistics there are similar results, 60 to 80 per cent of the cases having been wounded by missiles of low velocity. The American statistics obtained from the assistant director, surgical service, A. E. F., show that wounds caused by missiles of middle and low velocity constitute about 80 per cent of all.

The results of a review of the French hospital records (summer, 1918) show the following percentages:

	Per cent
Shrapnel or shell fragments	50. 66
Grenades	1. 02
Rifle or machine gun bullets	34. 05
Bombs from airplanes	. 10
Mine explosions	. 15
Accidental missiles, undetermined	14. 00

A more careful analysis of these cases would probably show that as many as three-quarters were due to missiles included under the limit of velocity noted above—that is, the equivalent physically of a 230-grain bullet traveling less than 1,000 feet a second. In this connection the American surgeon, Dr. Walter Martin, who traveled on a special mission for the American Army, found on the Western Front (1916–17) a "large proportion of the wounds examined were due to missiles of low and middle velocity." And surgeons agree that it is nearly always possible to determine from the nature of a fresh lesion whether it was caused by a missile of this character.

Summarizing the situation, it may be stated that the proportion of wounds due to middle and low velocity projectiles is not less than 60 per cent of all cases. This, in fact, is the least estimate the writer has been able to gather from medical experts in various services, some of whom declared emphatically that this percentage is entirely too small; that as many as 95 per cent of the wounds would usually fall within the limits given above. It is pointed out, for example, by Col. Joseph A. Blake, director of one of the largest American military hospitals (April 30, 1918) that the statistics as given above deal only with one class of wounded, for "a large number whose injuries are not infected are returned at the front and are not entered in the statistics of the hospitals." It is clear, therefore, that had armor been worn generally in the war a large number of the wounded would have been saved by its use; consequently its importance as a practical means of life-saving deserves full recognition. Moreover in numerous cases armor might have saved its wearers from missiles of high velocity which impinged obliquely, and were capable, therefore, of being deflected—an important consideration, since only a smaller proportion of missiles would be apt to impinge upon an object in a direct axial line.

FREQUENCY IN THE LOCATION OF WOUNDS AND ITS BEARING ON THE ARMOR PROBLEM

If it could definitely be established that a certain region of the body is particularly susceptible to injury, it is that region obviously which should be protected by armor. A curve of frequency in wounds with respect to their

[a] Two hundred and thirty data from English hospitals, obtained through the courtesy of Capt. I. S. St. C. Rose and of Captain Leeming, of the Trench Warfare Division, Ministry of Munitions, London.

location is to be examined, therefore, in order to determine the probable usefulness of body defenses. The study of hospital statistics in this connection might[a] furnish practical hints, and from this viewpoint the hospital records have been studied, especially of the French front. From an examination of the records of the French Medical Department (report from Col. Walter D. McCaw, M. C., United States Army, June 30, 1918), wounds have been classified according to their anatomical situation and percentage of their occurrence as follows:

	Per cent		Per cent
Head	11.90	Forearm	10.75
Thorax	7.25	Hand	8.95
Spine	2.20	Thigh	15.62
Abdomen	3.97	Leg	17.84
Arm	14.07	Foot	7.45

This indicates that 41 per cent of the casualties suffered from leg wounds, 34 per cent from arm wounds, and head and trunk each about 12 per cent.

A comparison of data obtained from various specialists has led to the belief that the following percentage tabulation of wounds with respect to their anatomical situation (hospital cases only) is not far wrong (up to 1918):

	Per cent		Per cent
Lower extremities	35	Head and neck	20
Upper extremities	25	Trunk	20

In a word, over 50 per cent of the hospital cases suffered from wounded extremities, and rarely more than a fifth of the patients were wounded in the head. The number of patients wounded in the abdomen is usually small, at first sight unexpectedly so. Abadie (d'Oran) in his studies of wounds of the abdomen, offers the following table:

Abdominal wounds	cases	479
Due to low-velocity projectiles	do	332
Due to high-velocity projectiles	do	147
Thorax	lung cases	15
Due to low-velocity projectiles	do	13
Due to high-velocity projectiles	do	2
Extracted		72
Bullets		33
Shrapnel fragments		39

To describe the various forms of body defenses classified as to their protective merits seems hardly the function of the present discussion. Their use was special. Not more than 2 per cent of the British soldiers at the front were provided with body armor. The French wore armor hardly in greater degree; the Germans on a scale of two suits of armor per company. At danger points this armor was used in considerably greater numbers. In this connection reference is made, however, to the work carried on by the British hospital service as suggested in the following diagrams, tabulating documents gathered toward the close of the war.[b] They indicate "areas of danger"

[a] But these statistics become readily controversial; our figures are based upon hospital cases only, the location of wounds on the dead of the battle field can not be determined.

[b] These were furnished the writer by the Trench Warfare Division, Ministry of Munitions, London (Captain Rose).

which would, of course, govern in a degree the wearing of armor, from the frequency of entry wounds. The first diagram (fig. 3) gives the topographical areas. The second (fig. 4), showing the anterior portion of the chest, indicates by dots actual entry wounds in 163 cases. In the last figure (fig. 5) there are shown by small dots entry wounds in chest and abdomen as recorded

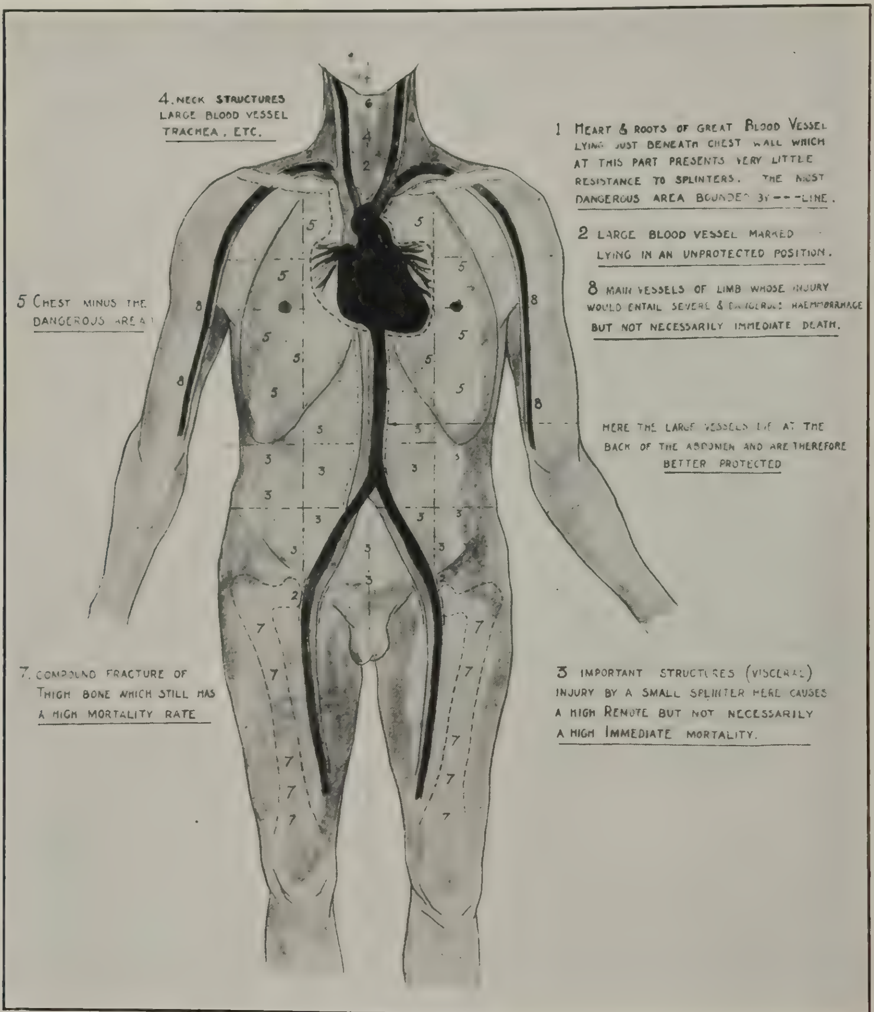

FIG. 3.—Diagram showing areas of danger. This and Figures 4 and 5 were made available through the courtesy of Capt. I. S. St. C. Rose, Trench Warfare Division, Ministry of Munitions, London

in about a thousand cases (163 thoracic, 834 abdominal), the deeper shading indicating the points of greatest danger.

A final word should be said about the degree of protection furnished by defenses (*a*) of metal and (*b*) of textile. It has long been known that various fibers, notably silk, show high ballistic resistance. In fact, much "soft armor" made its appearance during the war. To this end the munitions bureaus of various countries made exhaustive experiments with silk, hemp, sisal, cotton,

hair, flax, kopak, balata, etc., with the result that the silk fiber was demonstrated to be the most effective. According to Captain Ley of the munitions board in London, the experiments conducted at Wembley in "fragmentation huts" showed that sample pads of silks gave even better results than plates of helmet steel of even twice their weight, keeping out 74 degrees of "medium shrapnel bullets at 600 foot-seconds." A British expert in this field (Mr. William A. Taylor) declares that pure woven silk gives "materially better

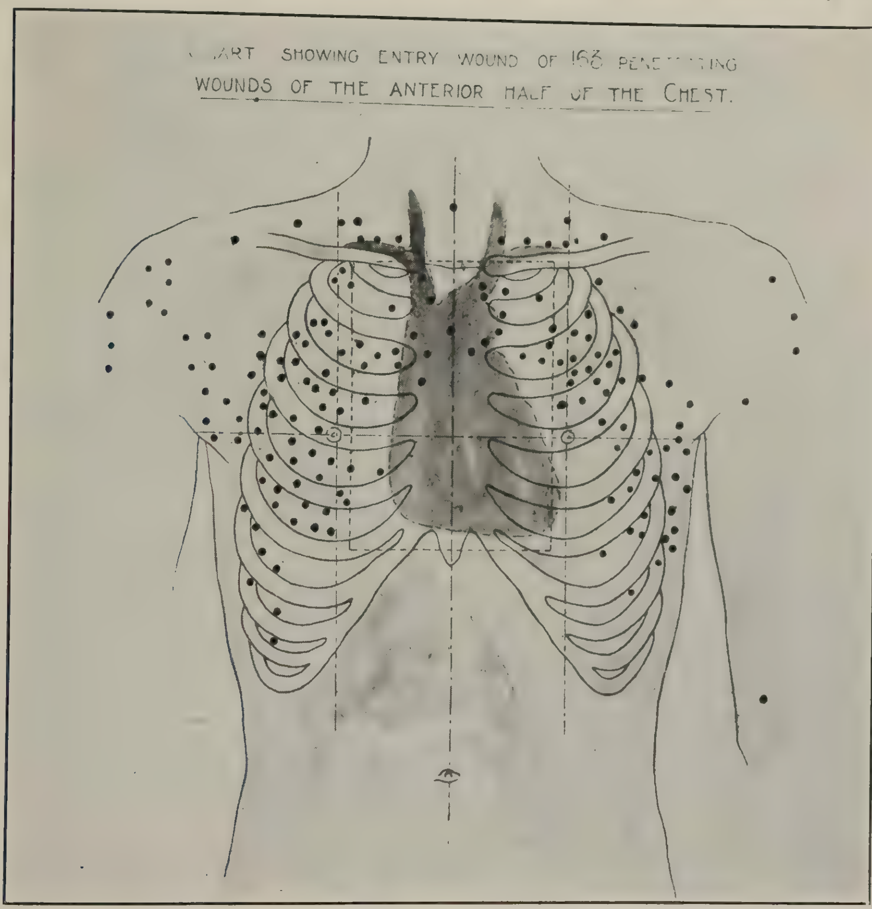

FIG. 4.—Diagram showing anterior portion of chest. Heart and roots of large vessels are indicated

results than manganese steel against shrapnel bullets up to a velocity of 900–1,000 foot-seconds, weight for weight." Also, "that silk weighing 10.8 ounces per square foot is proof against shrapnel at 800 foot-seconds, whereas steel to give the same resistance would weigh about 20 ounces. The relative advantages and disadvantages of silk as compared with steel for body armor may be summarized as follows: Silk does not give nearly the same resistance as steel against high velocity pointed projectiles (e. g., rifle bullets) or bayonet thrusts, but, on the other hand, it does not deform the bullet which perforates it. The bullet which passes through steel is always deformed and causes the

more serious wound. Against low-velocity blunt projectiles (e. g., shrapnel shell, splinters, bomb fragments) up to a certain velocity, silk is superior to steel, weight for weight." In general, however, the results of the English were by no means convincing to American observers. The latter declare that the "fragmentation hut tests" of the English do not furnish accurate data. The object thus tested is, or is not, struck, directly or indirectly, as the hazard of

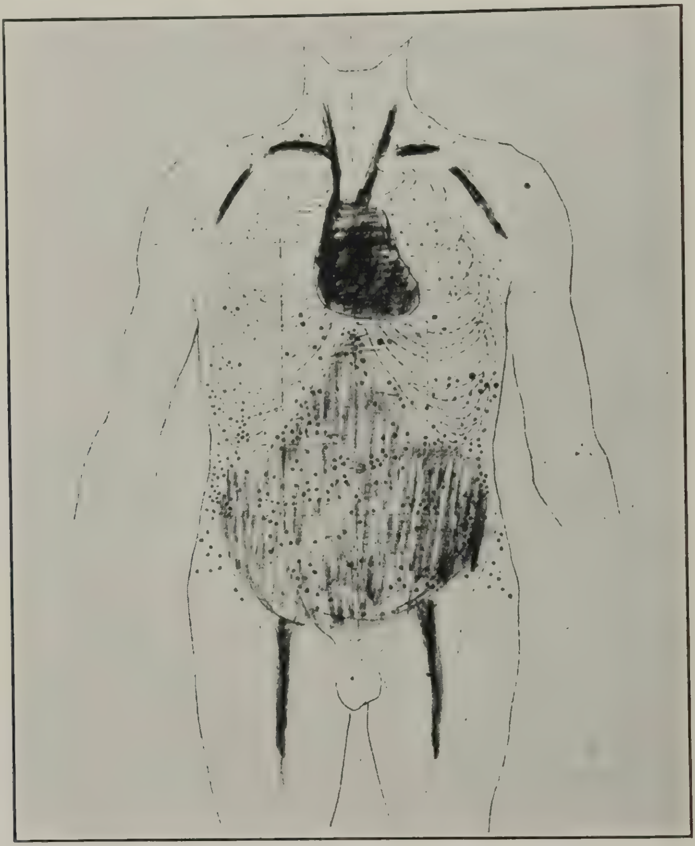

FIG. 5.—Diagram indicating by small dots entry wounds in chest and abdomen as recorded in about 1,000 cases (163 thoracic, 834 abdominal). The deeper the shading as here indicated, the greater the danger

the exploding bomb of shrapnel dictates. American tests, on the other hand, were made with ball of uniform weight which was shot directly at the object to be tested, with an explosive so graduated as to insure a definite impact. Hence we are firmer in our faith that the textiles are by no means better body defenses than plates of metal, weight for weight. We admit, however, that textiles have a definite value in preventing injuries from splash of lead or from smaller fragments produced by a crumbling projectile.

CHAPTER II

FIREARMS AND PROJECTILES; THEIR BEARING ON WOUND PRODUCTION

The military surgeon, during the World War, had brought to his attention, in his treatment of wounds, many factors of which the experience of previous wars had furnished few or no data, and to which the experience of civil surgical practice had contributed almost nothing. The effects of direct shock and of secondary missiles from high-explosive shells, of multiple wounds from machine-gun fire, and the exaggerated effects of pointed rifle bullets of very high velocity were the chief factors of which previous military and civil experience had given little or no suggestion. It is true that considerable experimental data, particularly concerning the effects of small-arm missiles, had been accumulated

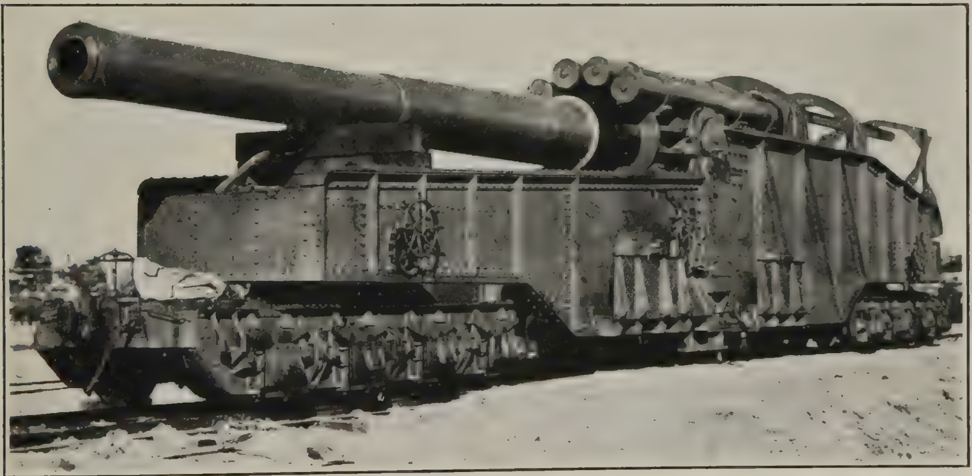

FIG. 6.—United States 14-inch railway artillery. This type was evolved entirely by the United States Ordnance Department. It is an excellent weapon for coast defense and hurls a 1,200-pound projectile more than 18 miles

which were corroborated by battle-field experience during the war, but unfortunately the experimental data, prior to the war, had been regarded as largely theoretical or at least lacking confirmation either in military experience or in big-game hunting. As a result, the surgeons of all armies, not only those drawn from civil medical practice but also those with previous experience in military surgery, found many conditions in the type and extent of the wounds encountered which they were unprepared to meet and unable to explain. And thus, early in the experience of each nation involved, the lives of many wounded men undoubtedly were sacrificed which might have been saved had the men come under surgical treatment at a period after the attending surgeons had become more familiar with actual wound conditions.

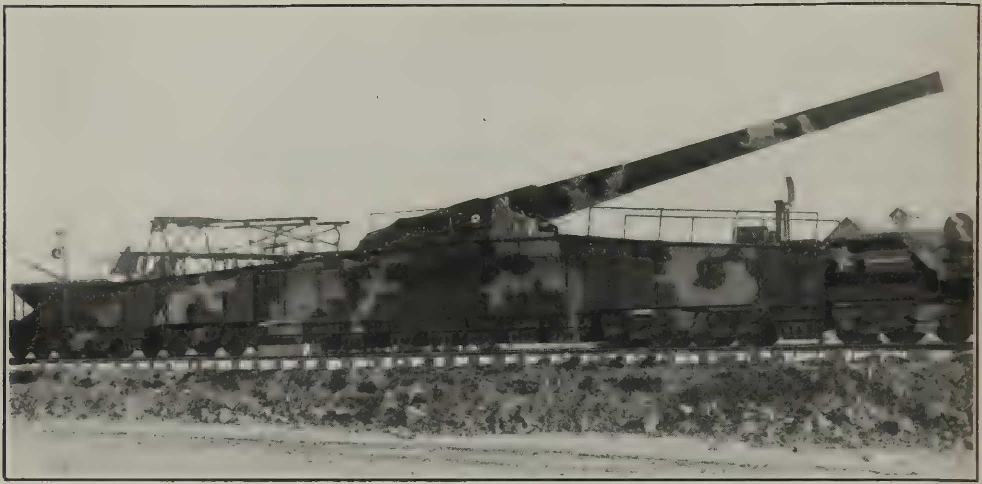

FIG. 7.—United States 12-inch rifle on sliding type railway mount. It is capable of hurling a 700-pound shell 25 miles. This is a modified Schneider type of carriage

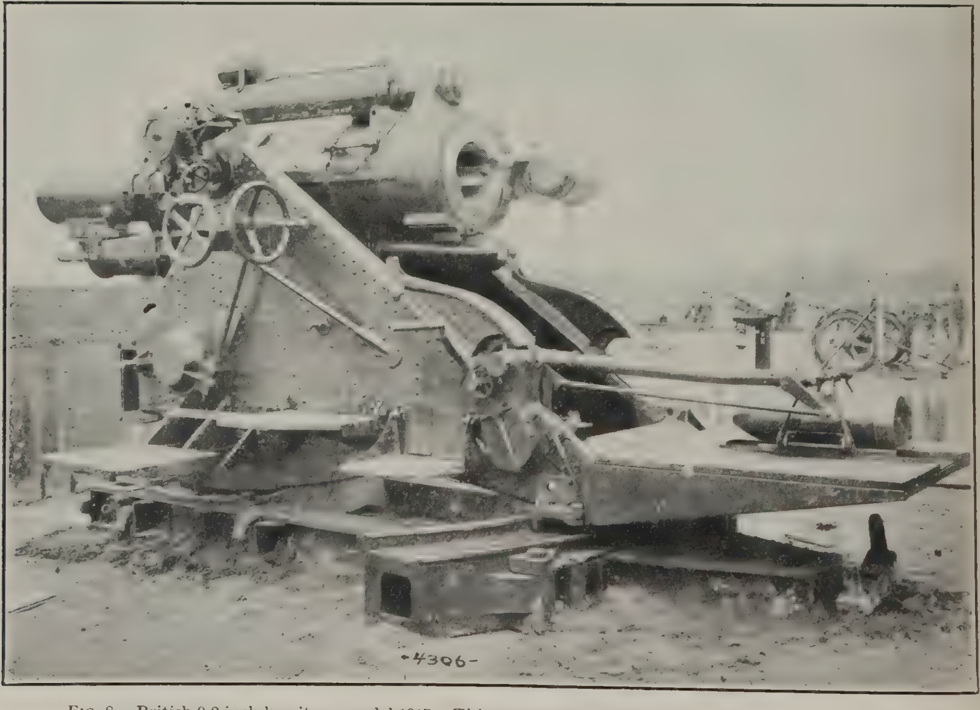

FIG. 8.—British 9.2-inch howitzer, model 1917. This gun shoots a shell weighing 290 pounds 8,690 meters

It is the purpose of this chapter to summarize the more salient facts, from the standpoints of weapons and missiles used by the several nations in their relation to wound production, and of pathology and physics which were learned from a study of war wounds.

ARTILLERY

The artillery used by the belligerents in the World War underwent various changes subsequent to the beginning of the war in 1914, and in consequence of the varying conditions along the front.[1] In the earlier months of the war, when the character of warfare was open, light mobile field guns were used almost exclusively on both sides, with the exception of the large siege guns and mortars used by the Germans to reduce Belgian fortifications.[1] The subsequent use of intrenched positions necessitated resorting to additional heavier guns.

The calibers commonly used by the Germans are given in Table 1.

FIG. 9.—United States 240-mm. howitzer, model 1918

TABLE 1.—*Some German guns and howitzers*[a]

Caliber, centimeters	Type	Weight of high explosive shell (pounds)	Maximum percussion range (yards)
7.7	Field gun	13–17	11,700
9.0	do	16.5	7,109
10.0	Gun	39.5	12,085
10.5	Light field howitzer	34.5	11,210
12.0	Gun	36	7,984
13.0	Light howitzer	89	15,748
15.0	Heavy field howitzer	92	10,936
21.0	Mortar	184–262	11,155

[a] Sources of information: (1) Data taken from S. S. 356, Handbook of the German Army in War, April, 1918. Issued by the General Staff (British—Ed.), 6/18. (2) Notes on German Artillery Matériel, I, Divisional Artillery, second edition, issued by second section, General Staff, American Expeditionary Forces, Nov. 1, 1918. (3) Ordnance Data, VI, European Artillery, German, memorandum supplied to Gen. J. H. Rice, chief ordnance officer, A. E. F., by Colonel Coles, and forwarded to Chief of Ordnance, Washington, D. C. Received Oct. 30, 1918. On file, Office of Chief of Ordnance, Ordnance Library, U F 520, XOO, Vol. VI.

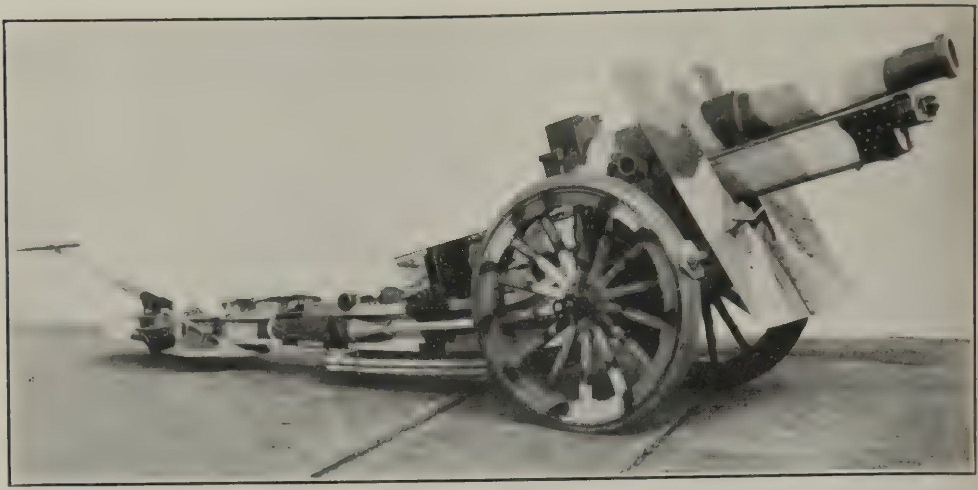

FIG. 10.—United States 155-mm. howitzer, model 1918 (Schneider). This weapon throws shell or shrapnel weighing 95 pounds. Muzzle velocity for shell is 1,420 feet per second

Besides the guns listed in Table 1, various trench mortars were in use by the Germans, the principal ones being given in Table 2.

TABLE 2.—*German trench mortars* [a]

Caliber, centimeters	Weight of high explosive projectile, pounds	Maximum favorable range, yards
Granatwerfer (stick bomb thrower)	4	208
3.9	1.7	700
7.6	9.9	1,422
17	92.6, 109.1, 123	1,750
24	220.5	1,312
25	207.2	1,094

[a] Source of information: S.S. 356, Handbook of the German Army in War, April, 1918. Issued by the General Staff (British—Ed.), B 18/145 4,000 6/18 H & S 5,586 wo, 103–105.

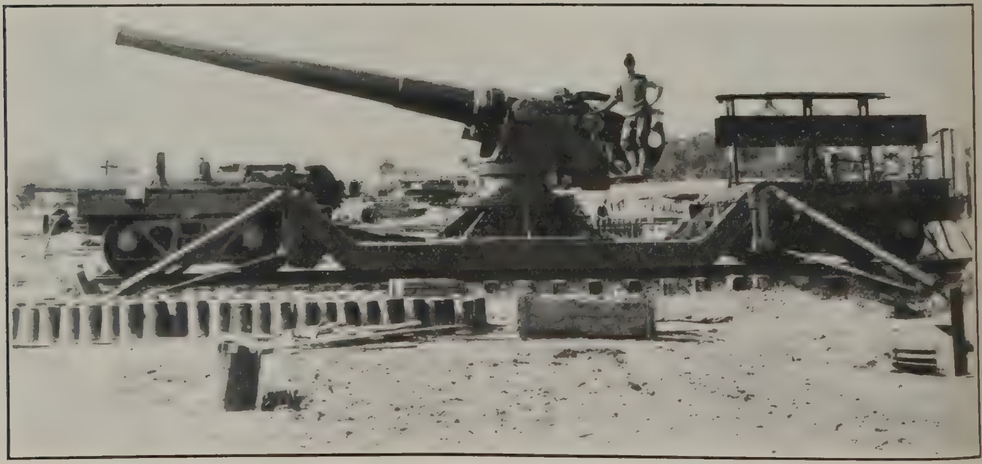

FIG. 11.—United States 7-inch Navy rifle mounted on a pedestal on a railway car. This rifle has a range of about 10 miles and throws a projectile weighing 165 pounds

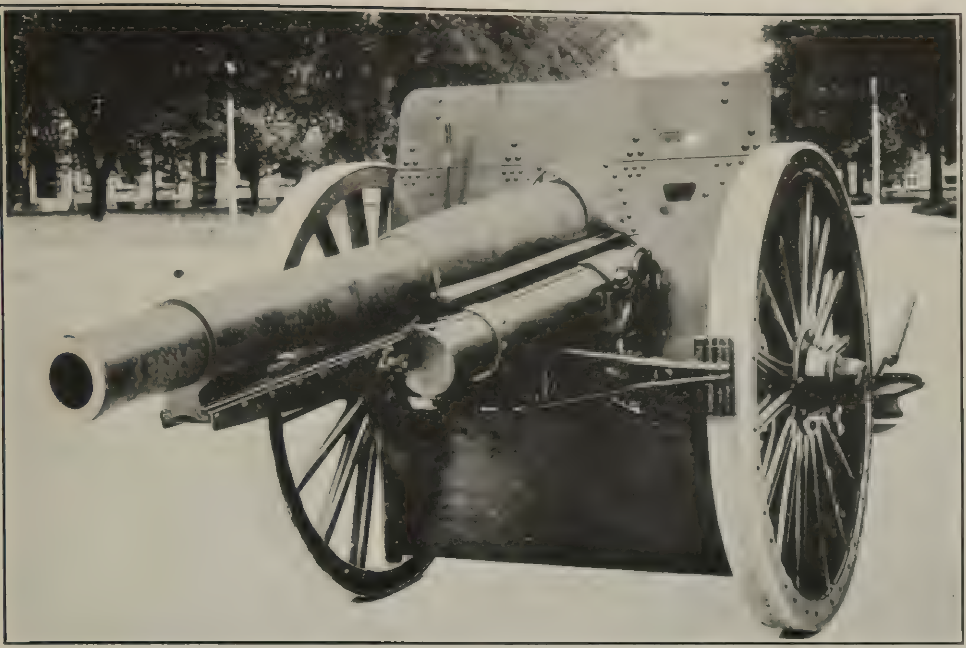

FIG. 12.—United States 4.7-inch gun and carriage, model 1906. This gun throws a projectile weighing 45 pounds a distance of about 6 miles

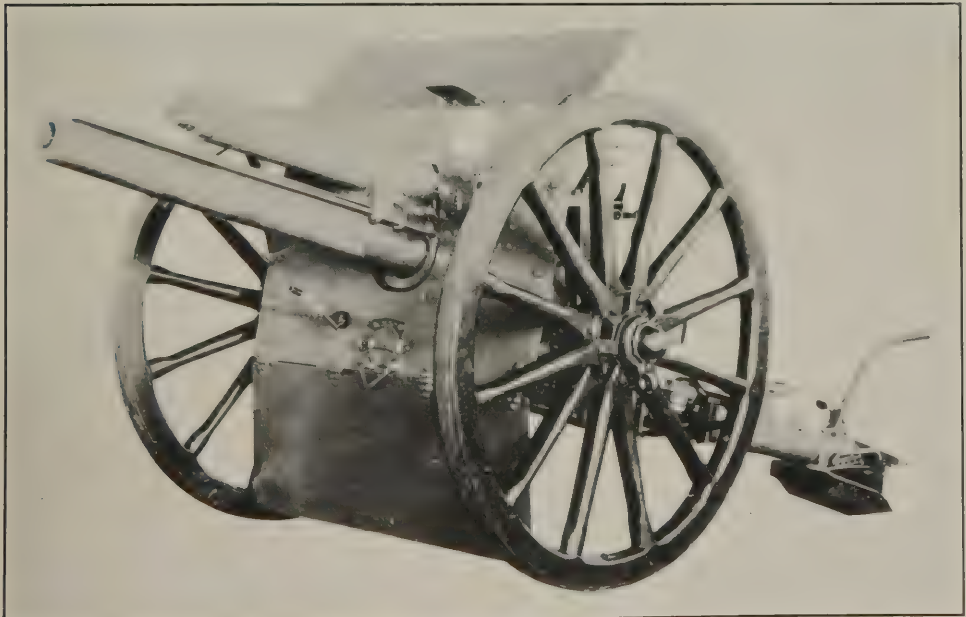

FIG. 13.—United States 75-mm. field gun, model 1917 (British). This gun throws a shell weighing 12.3 pounds a distance of 8,300 meters, with a muzzle velocity of 1,750 foot-seconds, and shrapnel weighing 16 pounds a distance of 8,900 meters, with a muzzle velocity of 1,680 foot-seconds

The German 7.7-cm., the French 75-mm., and the British 3.3-inch (18-pounder), all of which were relatively light field guns, were the most used by these three armies;[2] the American forces used almost entirely the French 75-mm.[3] field gun. In the later stages of the war, heavy artillery came more and more into use. Of the heavier types the French 90-mm., 105-mm., 120-mm., 155-mm., and the 220-mm.,[1] and the British 5-inch gun and 6-inch, 8-inch, and 9.2-inch howitzers,[4] together with a considerable number of large caliber naval guns usually mounted for land operations on railway carriages, came into general use.[1]

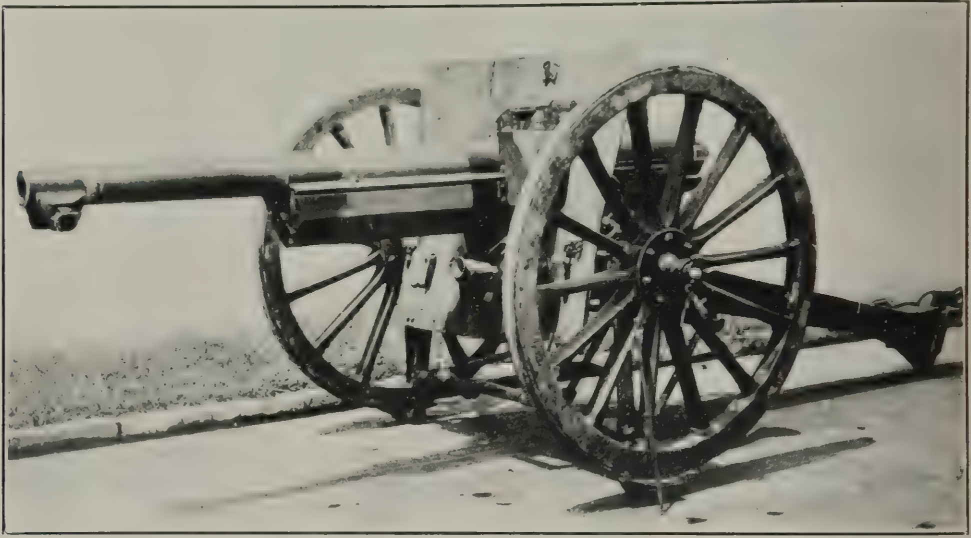

Fig. 14.—French 75-mm. field gun. This type of gun has been used by the French Army since 1897 and was the gun most used by the Allies in the Great War. This gun throws a shell weighing 12.3 pounds a distance of 8,400 meters, with a muzzle velocity of 1,805 foot-seconds, or shrapnel weighing 16 pounds a distance of 9,000 meters, with a muzzle velocity of 1,755 foot-seconds

ARTILLERY PROJECTILES

The shape and weight of artillery projectiles are determined largely by ballistic factors which only remotely affect the wounding capacity. The thickness and tensile strength of the wall must be sufficient to prevent destruction or fracture by the firing and rotational stresses. Once this condition is attained the thickness and fracture-index of the walls and the amount and character of the shell contents are designed to produce the greatest destroying effect for which the shell is to be used.

As used during the World War, artillery ammunition consisted of shrapnel, high-explosive shell, armor-piercing shell, or special shell such as gas shell, incendiary shell, smoke shell, and star shell.

SHRAPNEL

Shrapnel shell is usually made as thin-walled as possible and still withstand firing and rotational stresses.[5] The largest number of bullets possible, of sufficient weight to maintain wounding energy, are packed within the shell cavity.[6]

During the war the artillery ammunition of each of the armies showed a considerable variation in the size and weight of the shrapnel bullets used in shells of different calibers. Table 3 will give some idea of the number in the shrapnel shells in the three most used light field guns.

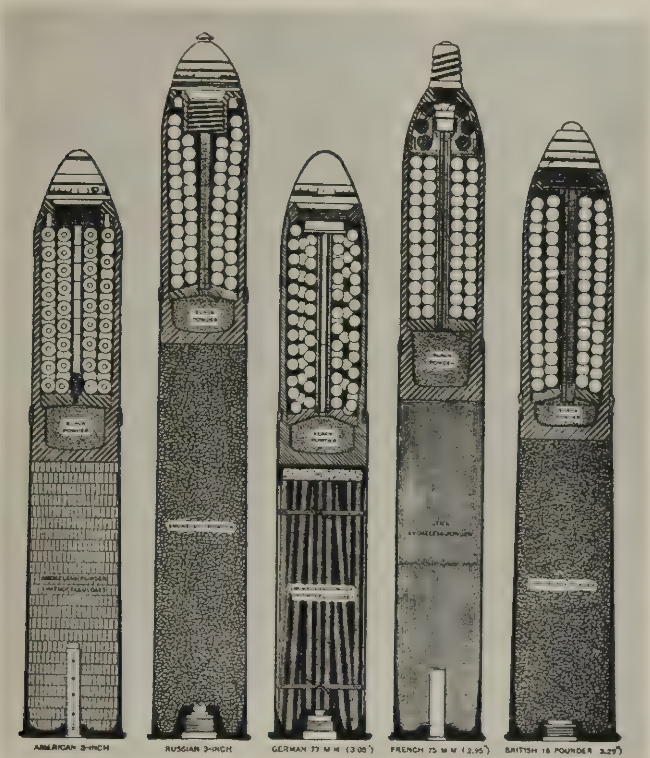

FIG. 15.—Types of shrapnel in modern use

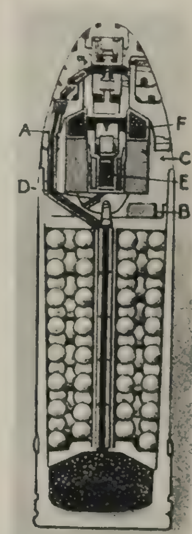

FIG. 16.—A type of the high-explosive shrapnel

TABLE 3.—*Shrapnel shell used in light field guns* [a]

Army	Caliber of gun		Approximate weight of shell, pounds	Muzzle velocity, foot-seconds	Approximate weight of one bullet, grains	Number of bullets in shrapnel shell
	Millimeters	Inches				
France	75	2.95	15	1,755	150	285
Great Britain	82.5	3.30	18.5	1,635	170	340
Germany	77	3.03	15	1,555	150	300

[a] Sources of information: (1) The Story of the 75 (75 millimeter field gun), by W. N. Dickinson, Washington, Government Printing Office, 1920, 5, 116, 117. (2) Schneider & Cie.: Services de L'Artillerie, Ateliers du Creusot, Du Havre et D'Harfleur, Matériel de Campagne, a Tir Rapide de 75-mm., type L. D. P., 1908, 7. (3) Handbook for the Q. F. 18-pounder Gun, MK IV. on Carriages, Field, MKS. III and III*, Land Service, 1919, printed by His Majesty's Stationery Office (London—Ed.), 10, 64, 65. (4) Ordnance Data, VI, European Artillery, German. Report on the comparative characteristics of German ammunition for 77-mm. Gun, models 1896 and 1916, dated Oct. 31, 1918, source unknown, and French translation of a German document, Headquarters, A. E. F., January, 1918. On file, Office of Chief of Ordnance, Ordnance Library, UF 520, XOO, Vol. VI. (5) Notes on German Artillery Matériel, I. Divisional Artillery, second edition, issued by second section, General Staff, American Expeditionary Forces, Nov. 1, 1918.

Shrapnel shell is designed primarily for man-killing, although frequently it is employed for destroying obstacles such as wire, billets, and so forth.[7]

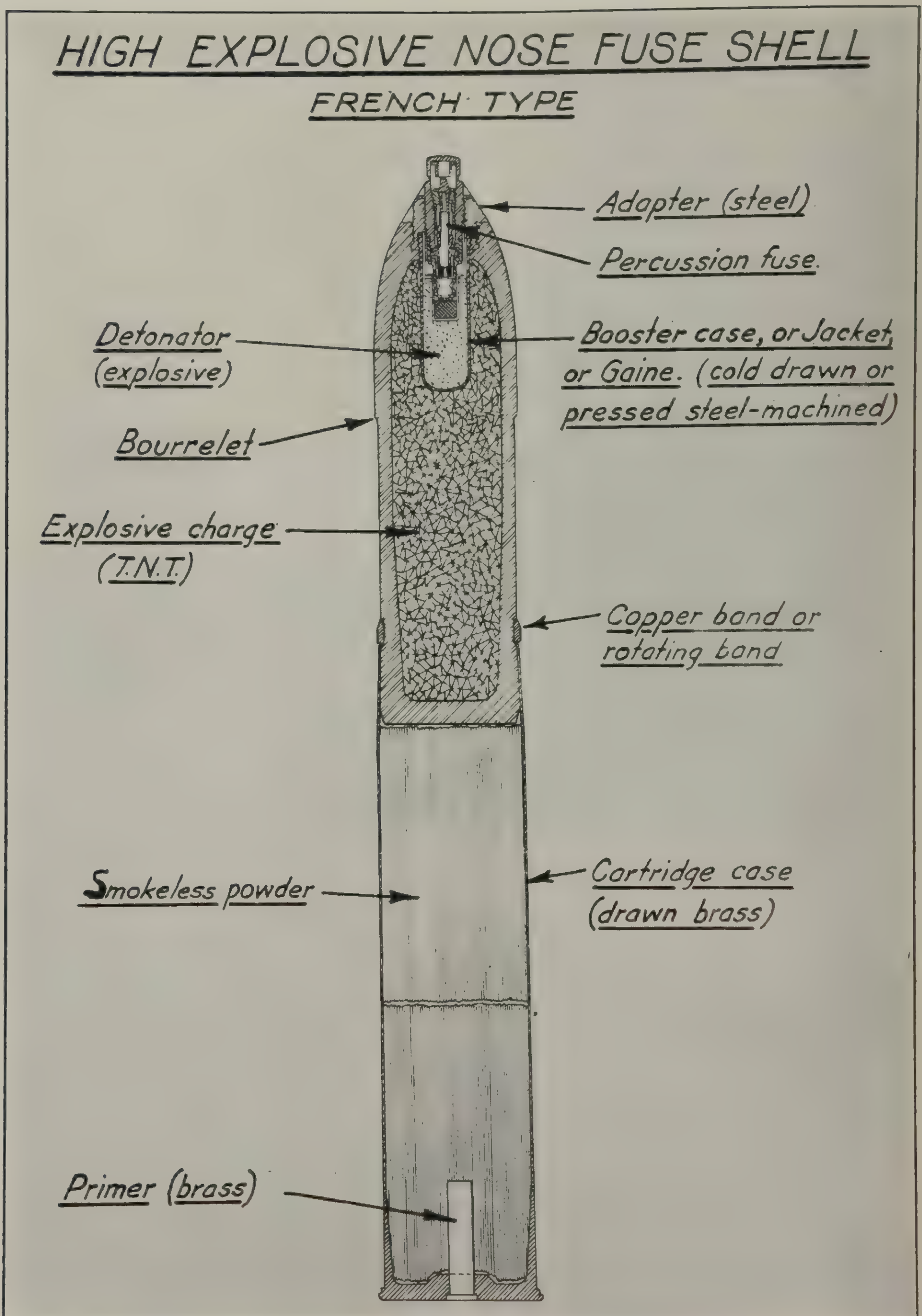

FIG. 17.—French 75-mm. high-explosive, nose-fuse shell

In shrapnel fire against men the shell is made to explode in the air so as to discharge in a compact mass.[8] The opening charge somewhat accelerates the velocity of the bullets (about 200 foot-seconds) at the moment of their release.[6]

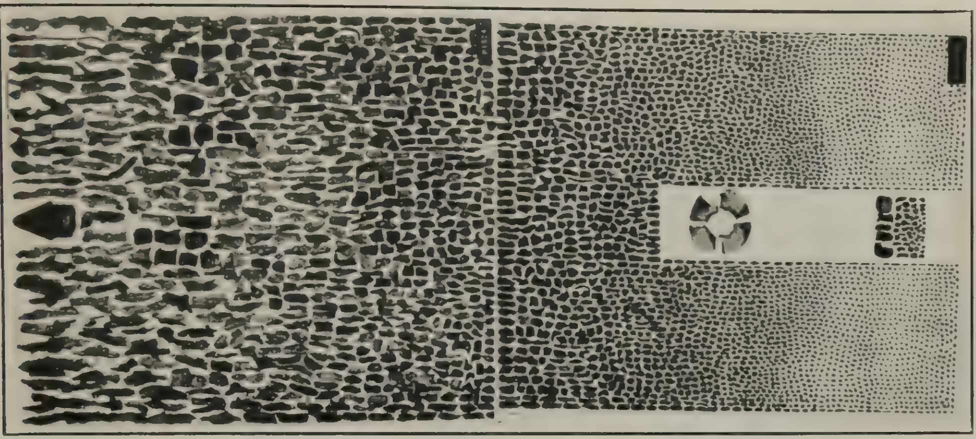

FIG. 18.—Fragmentation of 10-inch common steel shell weighing 221 pounds. Total number of fragments recovered, 4,078

The height and angle of descent of the shell at the moment it is opened determines in large measure the angle at which men are struck and also accounts to some extent for the large proportion of wounds in the upper exposed parts of the body. The chief function of the steel helmet is protection from this overhead shrapnel fire.

Shrapnel shells are generally made of forged steel with high tensile strength, and when used with bursting charges of low energy are not fragmented.[5]

HIGH-EXPLOSIVE SHELL

The high-explosive shell, as its name implies, contains a large destructive charge of some high explosive.[9] It is made in two general types,[10] either with

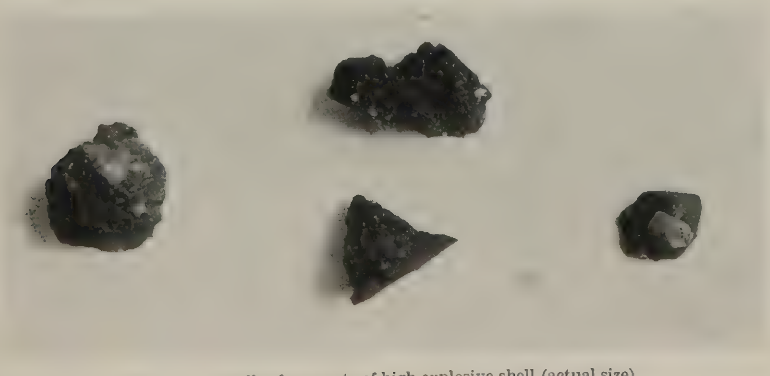

FIG. 19.—Smaller fragments of high-explosive shell (actual size)

thick strong walls and relatively reduced amount of explosive for the production of man-killing splinters, or with relatively thin walls and a very large explosive content for cutting wire entanglements, destroying dugouts, buildings,

and so forth. The German 77-mm. high-explosive shell had a thick casing and contained a relatively small charge (about 135 gm. of picric acid).[11] On detonation about 500 fragments were produced, varying in weight from 10 to 200 gm., with an initial velocity of from 300 to 400 meters a second.[11] The

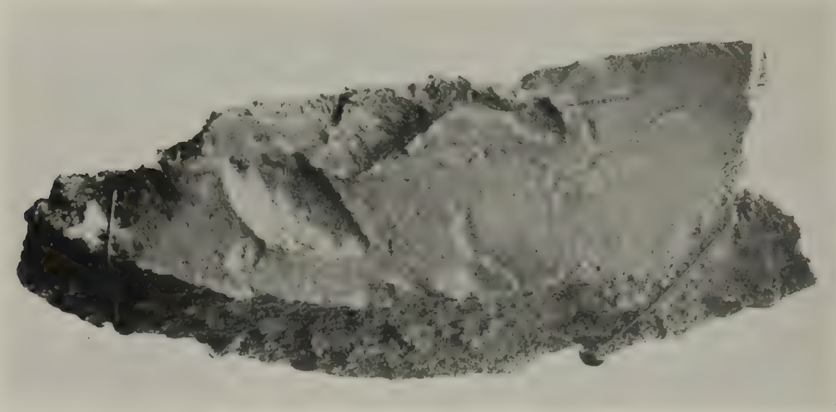

FIG. 20.—Actual size of fragment of high-explosive shell removed from lower jaw

French 75-mm. shell had a thinner casing and carried a heavy charge, about 825 gm. of melinite.[11] On detonation this shell burst into about 2,000 small splinters with a very high initial velocity of approximately 1,000 to 1,200 meters a second.[11]

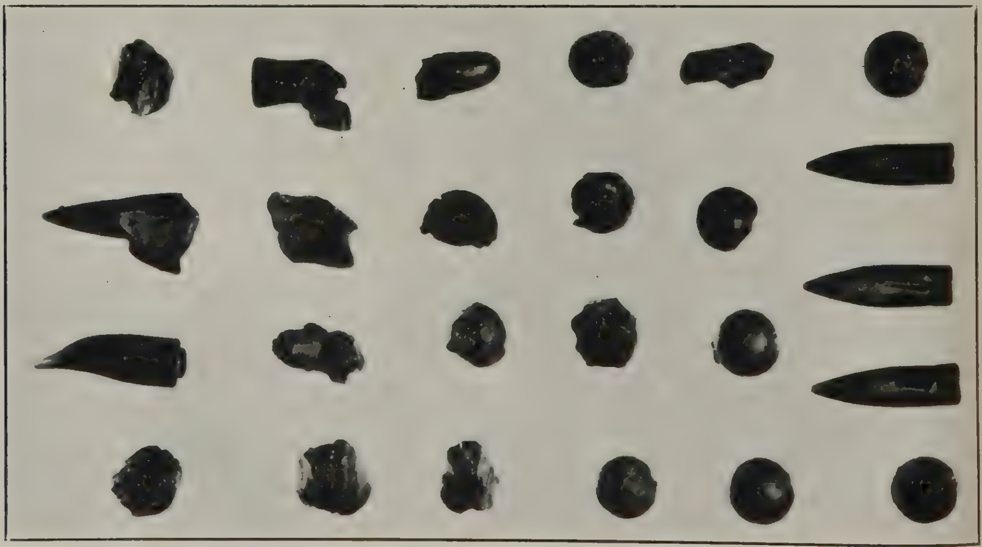

FIG. 21.—Shrapnel and rifle bullets removed from wounds

Small splinters from high-explosive shell, owing to their relatively low specific gravity as compared with shrapnel ball and the high air resistance due to their irregular shape, rapidly lose their velocity and do not fly far. It is ordinarily estimated that the best man-killing weight of splinters from the

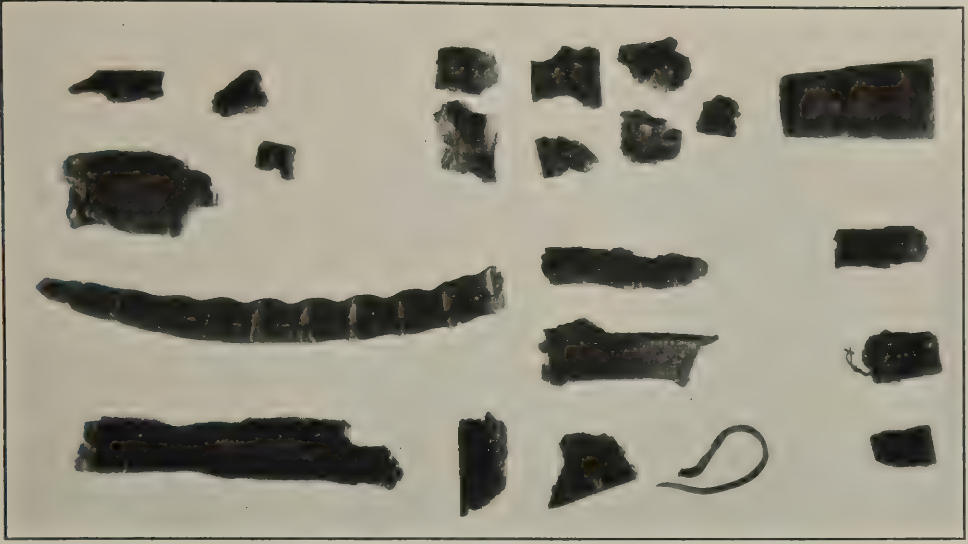

FIG. 22.—Shell fragments removed from wounds

FIG. 23.—Portion of casing of 210-mm. high-explosive shell, with piece of olive-drab cloth still adherent, removed from wound

high-explosive shell is about 25 gm., although splinters lighter than 10 gm. may be very effective near the point of explosion.[12] The German 7.7-cm. high explosive shell weighing about 15 pounds was designed to give 135 splinters of an average weight of 50 gm.[12] The French 75-mm. high-explosive shell, weighing about 12 pounds, was designed to give only 50 splinters averaging 100 gm. in weight.[12] The effectiveness of this shell depended on the high velocity near the point of explosion of the very large number of small splinters into which it was fragmented. This shell was highly effective over an area of about 25 square meters.[12] The German 7.7-cm. shell was less thoroughly effective over a considerably larger area.[12]

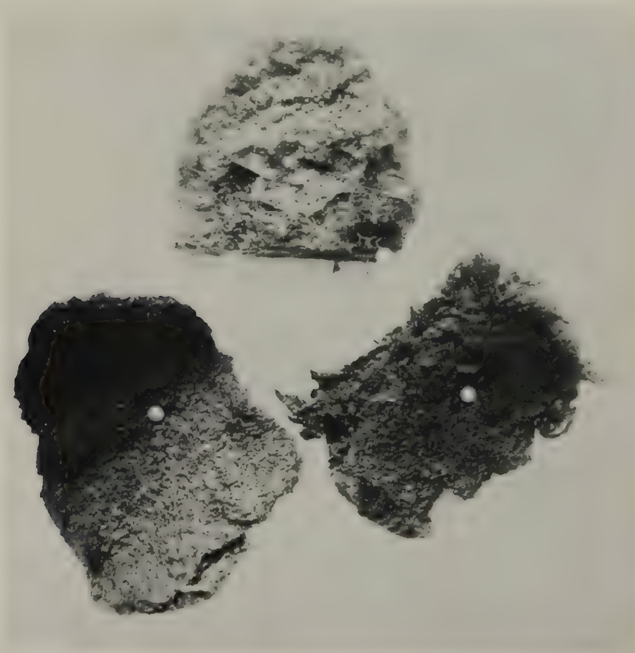

FIG. 24.—Piece of shell (above) and two pieces of cloth (below) removed from a shell wound of the back, having some fibers of cloth still clinging to piece of shell. Actual size

Besides the steel splinters from high-explosive shells, the surgeon sometimes encountered other metallic missiles from the same source which he was at a loss to explain. The shell fuses for igniting the bursting charge contained a number of cast or machined metal parts; on the bursting of the shell these frequently caused wounds of unusual type. In addition, when the annealed copper driving rings which surrounded shells were blown apart, they were likely to remain as long strands of metal with terrific wounding power. The Germans employed on their shells, behind the driving rings, various types of decoppering rings.[13] These were of aluminum or tough alloys, such as zinc-aluminum or tin-lead, and they acted very much like the copper driving rings as wounding agents, although they were smaller and usually of lower specific gravity.

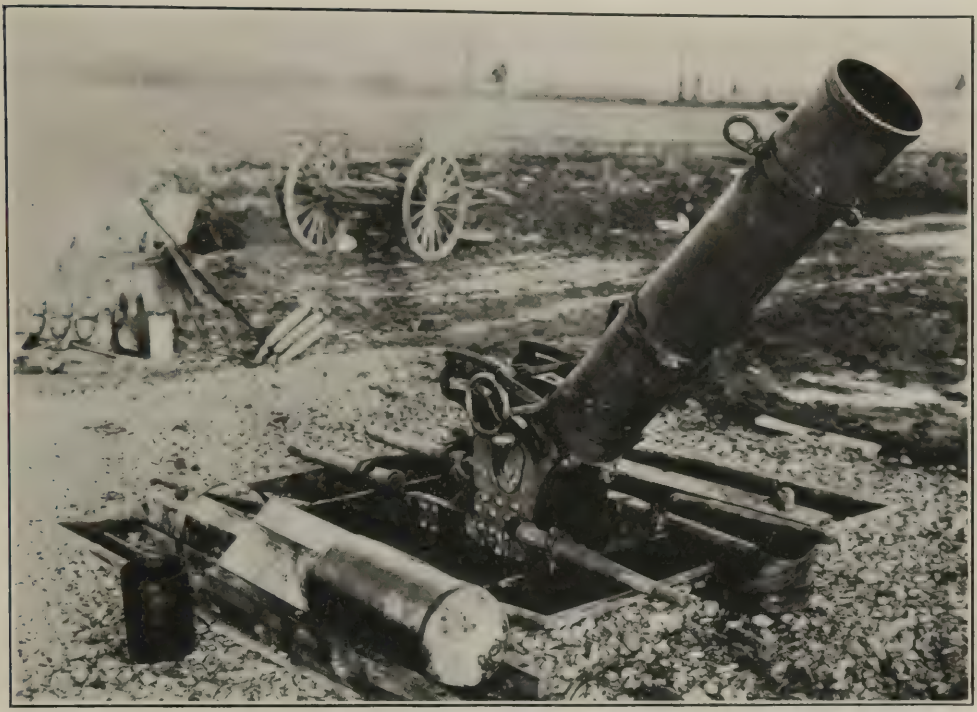

FIG. 25.—Trench mortar, 240-mm. (9.45-inch)

FIG. 26.—Stokes 4-inch trench mortar and ammunition

The common belief that poisonous gases were generated by the detonation of high-explosive shells was erroneous. Small quantities of carbon dioxide and carbonic oxide were generated. These were quickly dissipated by the terrific air currents following detonation.

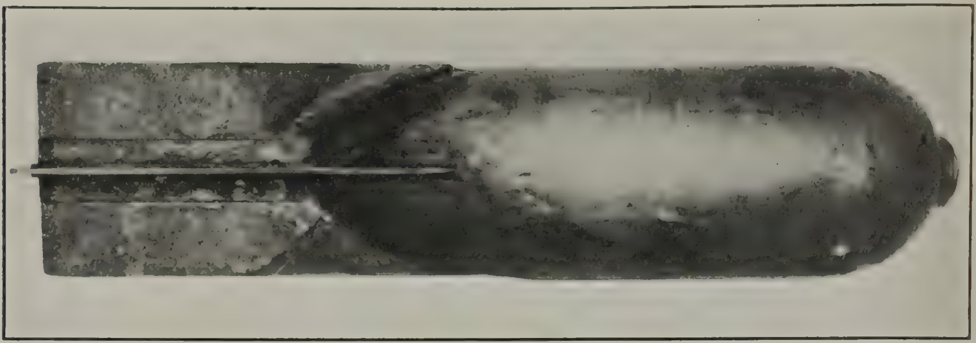

Fig. 27.—Trench mortar shell, 240-mm.

Though shrapnel and high-explosive shells were issued in equal proportions to the French artillery early in the war, as the war progressed high-

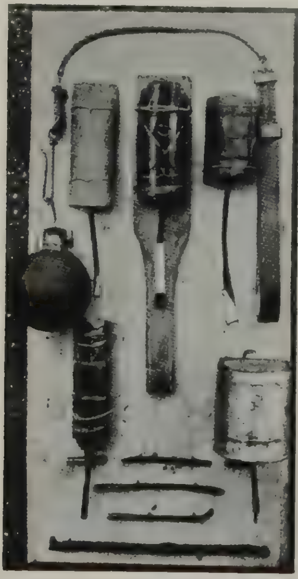

Fig. 28.—Regulation French bracelet type of hand grenade and a number of extemporized types, such as the "racquet" and "jam-tin"

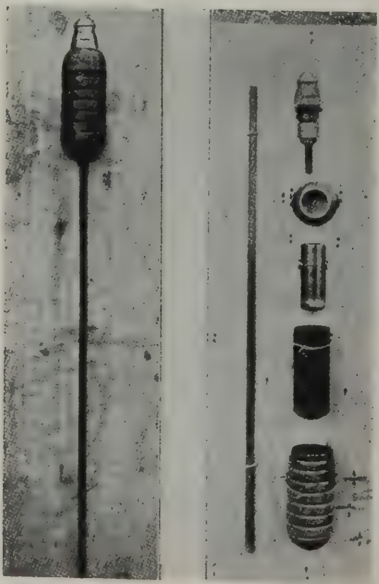

Fig. 29.—German combination grenade for hand or rifle use

explosive shell was predominant.[14] Efforts were made by all of the warring nations to develop a "universal" shell which would effectively deliver shrapnel ball and also produce wounding fragments by rupture of the casing.[15] One such type of universal shell was so arranged that when the shrapnel balls were

FIG. 30.—English combination grenade used in the rifle

FIG. 31.—English combination grenade

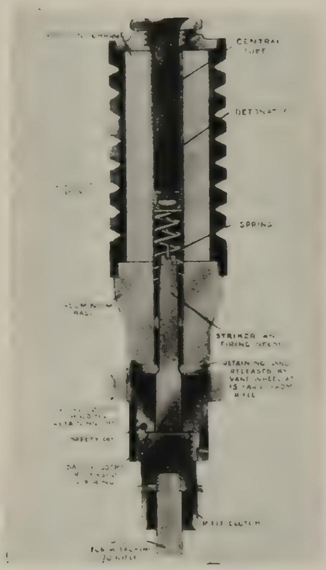

FIG. 32.—Longitudinal section of an English grenade

FIG. 33.—United States hand grenades. From left to right, defensive, offensive, gas, phosphorus

released in the air the head of the shell, which itself contained a high-explosive charge, was blown off and fragmented by explosion on striking any object.[15]

The consideration of armor-piercing, gas, incendiary, smoke, star, and other special shells is outside the scope of this chapter, since they were not primarily designed as wounding missiles.

Shells fired from heavy trench mortars—for example, the 240-mm.—were thin-walled, of low velocity and short range. They had large charges of high explosive. Though the detonation of these shells produced serious concussion in their immediate vicinity, and their moral effect was very considerable, the penetration power of secondary missiles from them was small.

HAND GRENADES

Two kinds of hand grenades were used during the war: A defensive grenade, made of stout metal which would fly into fragments when the interior charge exploded; an offensive grenade made of paper, the purpose being to produce a deadly effect by the flame and concussion of the explosion itself.[16] The defensive, or fragmentation, type of grenade was the most commonly used of the grenades, and ordinarily was thrown by men in the trenches, the walls of which protected the throwers from the flying fragments. On the other hand, though the offensive grenade was quite sure to kill any man within three yards of it when it exploded, it was safe to use in the open, there being no pieces of metal to fly back and strike the thrower.[16]

The wounding effect of grenade fragments, especially at short ranges in trenches, was very considerable;[17] however, the fragments rapidly lost their velocity and consequently their wounding energy. Grenade wounds were almost always infected.[18]

RIFLE GRENADES

The rifle grenade, used both as a defensive and offensive weapon, fits in a holder at the muzzle of an ordinary service rifle.[19] When the rifle is fired, the bullet passes through a hole in the middle of the grenade, and the gases of the discharge following the bullet throw the grenade approximately 200 yards.[19] The effective area of an exploding rifle grenade is 75 yards.[19]

AIRPLANE BOMBS

All of the bombs used by our aviators and by the aviators of other nations were of three distinct types: Demolition, fragmentation, and incendiary bombs.[20] The demolition bombs were for use in destroying matériel, and all sorts of heavy structures where a high-explosive charge was desired; consequently they were of light steel, which was filled with some explosive of high destructive power.[20] The fragmentation bombs differed from the demolition bombs in having a thick wall and a smaller charge of explosive.[21] The shell walls were likely to separate into thin slivers, with very sharp edges, which produced lacerated wounds.

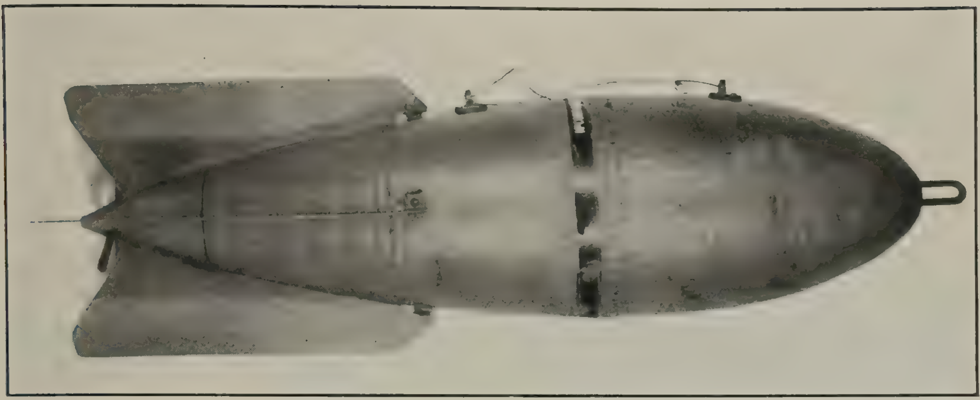

FIG. 34.—Demolition bomb, 25-pound, carrying 125 pounds of explosive, and having heavy cast-steel nose and pressed sheet-steel rear body, for airplane use

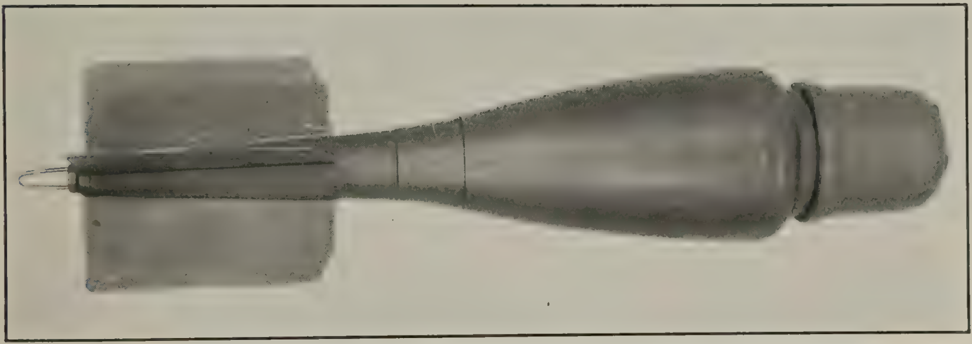

FIG. 35.—Fragmentation bomb, 25-pound, carrying 3 pounds of explosive, designed for use by airplanes against troops

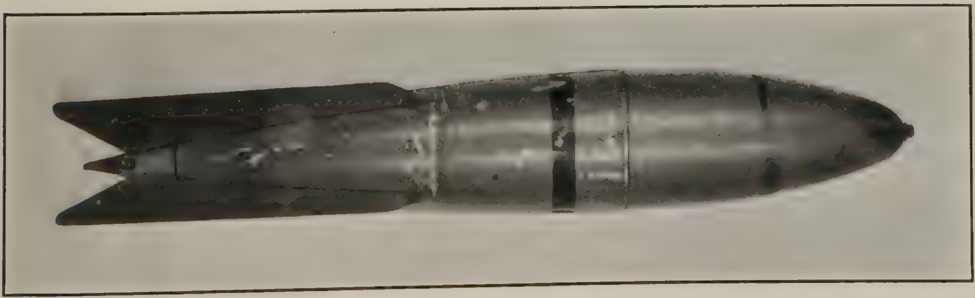

FIG. 36.—Incendiary bomb, 40-pound, of the intensive type, with steel nose and fusible zinc rear casing, for airplane use

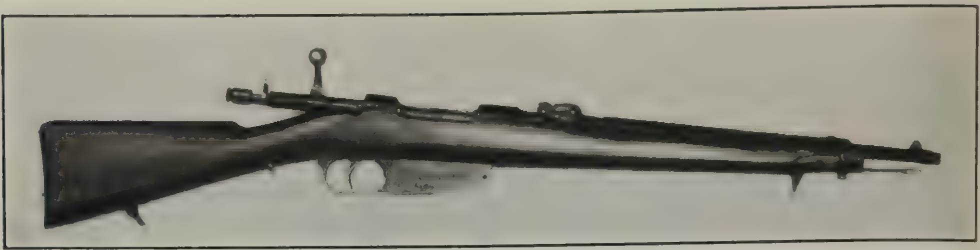

FIG. 37.—Italian Mannlicher rifle, model 1891. This rifle with 30.75-in. barrel weighed 8.41 pounds. The carbine shown here, with 18-inch barrel with which Cavalry and Alpine troops were armed weighed barely 6 pounds

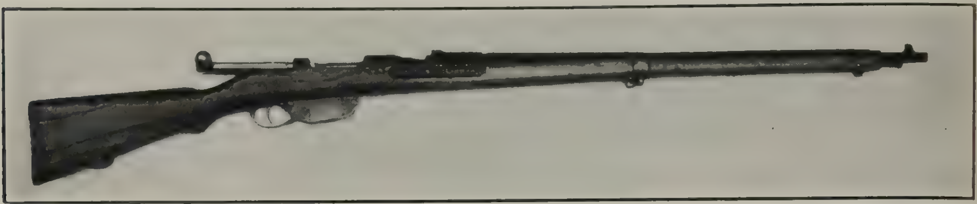

FIG. 38.—Austrian straight-pull Mannlicher rifle, model 1895. The bayonet for this rifle had a blade 10 inches in length

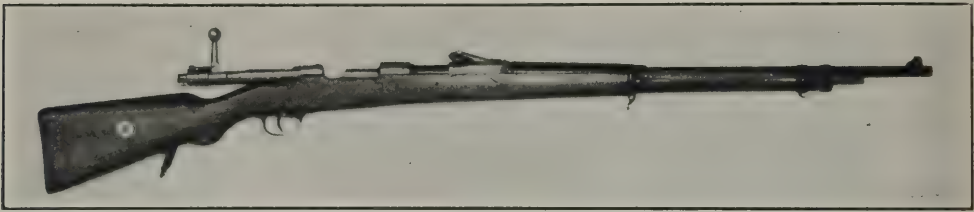

FIG. 39.—German Mauser rifle, model 1898. The muzzle of this rifle was fitted with a cover which is not shown in the cut. The bayonet is "D" in Figure 74

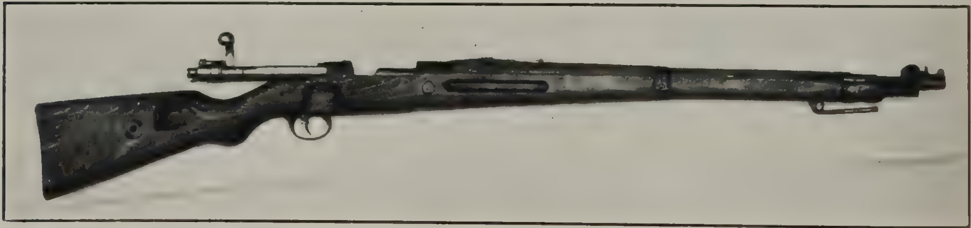

FIG. 40.—German short rifle, model 1898. This rifle had the bolt turned down. The muzzle cover is shown in place. The sling passed through a loop on the left of the lower band and was fastened on the right side of the buttstock after passing through a recess just back of the grip

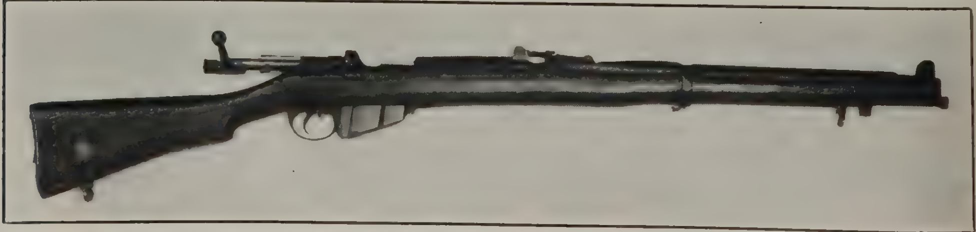

FIG. 41.—English short Lee-Enfield rifle, model 1907. The hump over the receiver is a clip guide. The heavy ears at the sides of the front sight were cumbersome but very useful as sight protectors

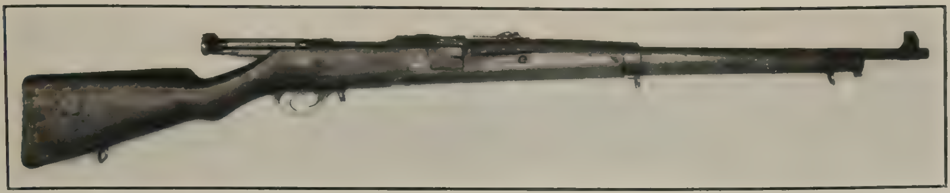

FIG. 42.—Canadian Ross magazine rifle, Mark III, model 1916. This was a straight-pull clip loader. The action was very fast, but had a tendency to stick under adverse conditions

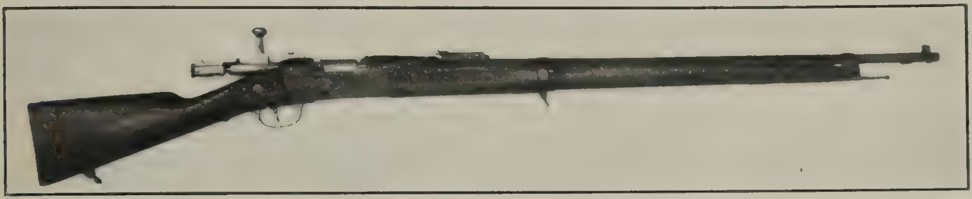

FIG. 43.—French Lebel rifle, model 1886–93. This rifle, the standard arm of the French Army at the beginning of the war, had a tubular magazine under the barrel

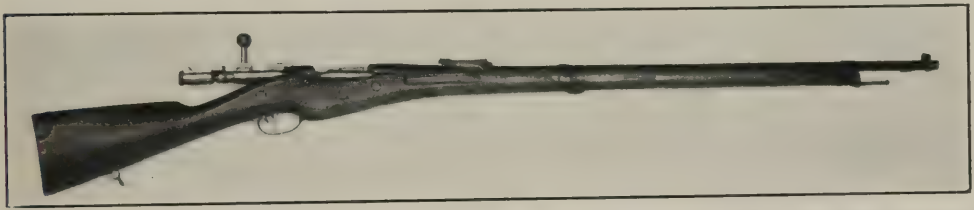

FIG. 44.—French Lebel rifle, model 1907–15. In this model a clip-loading magazine under the receiver was substituted for the cylinder magazine of the 1886–93 model; otherwise the gun was practically the same as the latter. The magazine holds three cartridges loaded in a clip

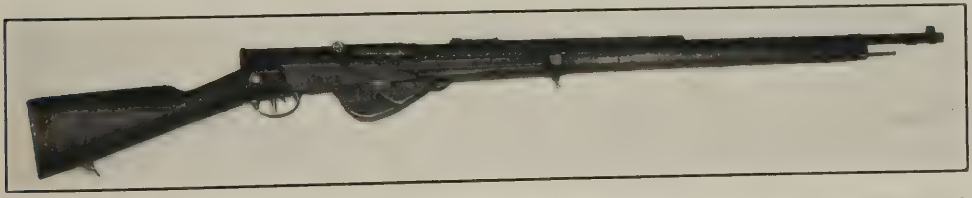

FIG. 45.—French automatic rifle, model 1917. This weapon closely resembles in its barrel and fore end the model 1886–93. It is gas operated and self-loading in action

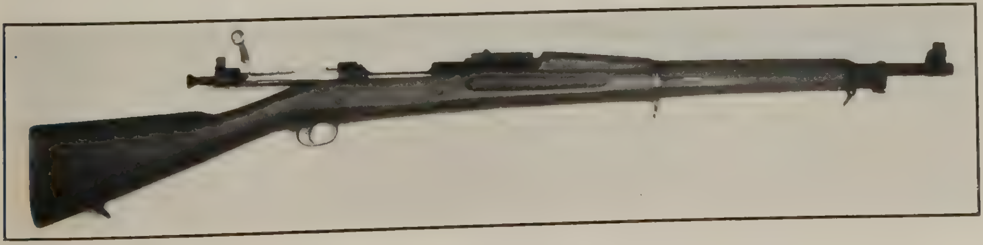

FIG. 46.—American Springfield rifle, model 1903

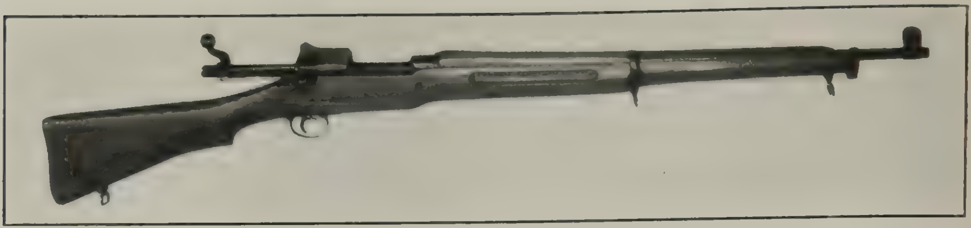

FIG. 47.—American Enfield, model 1917. This gun was an adaptation of the British Enfield model 1914 design. It was substituted for the Springfield in equipping American troops because there was abundant machinery or its manufacture already in existence in the United States in the spring of 1917, while there was not sufficient machinery in existence for the manufacture of a proper supply of the Springfield, model 1903

FIG. 48.—Japanese Arisaka rifle, model 1907, officially known as the "Thirty-eighth year model." Many of these rifles were sold by Japan to both Russia and England during the war and hence were in use in Europe

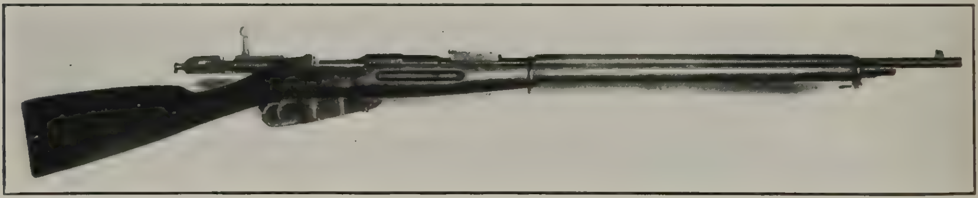

FIG. 49.—Russian Mouzin rifle, model 1901, officially known as the "3-line Nagant." This was a heavy, clumsy weapon of doubtful accuracy and reliability. It was made in large numbers for Russia by manufacturers in this country. Many of them still remain in the United States

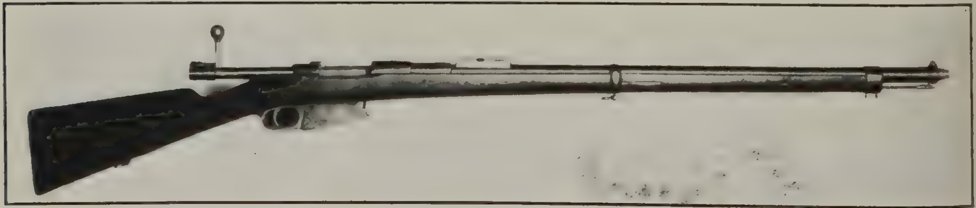

FIG. 50.—Belgian Mauser rifle, model 1889. This model had a metal tube protector covering the barrel

SMALL-ARMS WEAPONS AND MISSILES

RIFLES

The chief infantry arm of each of the warring nations in the World War was a rifle of a comparatively old model.[22] The French Army of 1918 carried the Lebel model 1886–1893 rifle.[22] The Italian Army carried the Mannlicher-Carcano rifle of the 1891 model.[22] The Austrian Army was armed with the 1895 Mannlicher.[22] The German Army carried the 1898 model Mauser.[22] The Russian 3-line rifle, model 1900, was only a slight modification of their old Nagant model.[22] The American Springfield was of the 1903 model [23]; the American 1917 model, modified British Enfield, was the most modern weapon.[22] The British Enfield model 1907 was slightly more recent than the American Springfield, but in 1914 the British Government considered it so obsolete that it had been planned to supersede it with a new model.[24] However, though all of these guns, except perhaps the two American models, were regarded as obsolete before the war began, they all stood the severe test of war service in a most satisfactory manner.[22] The chief characteristics of the principal rifles in use are shown in Table 4.

TABLE 4.—*Characteristics of the principal rifles used in the World War* [a]

Country	Model	Designation	Magazine system	Number of cartridges in magazine	Charger or clip	Weight without bayonet, pounds	Weight with bayonet, pounds
Austria	1895	Mannlicher	Fixed vertical box	5	Clip	8.34	8.98
Belgium	1889	Mauser	Detachable vertical box	5	Charger	8.03	9.59
Canada [b]	1907	Ross	Fixed vertical box	5	Neither	8.06	9.08
France [c]	'86–'93	Lebel	Cylindrical in fore end	8	do	9.24	10.12
	1890	Lebel (carbine)	Fixed vertical box	3	Clip		
Germany	1898	Mauser	do	5	Charger	9.00	9.88
Great Britain	1907	Lee-Enfield Mark I	Detachable vertical box	10	do	9.25	10.22
	1907	Lee-Enfield Mark III	do	10	do	8.66	9.66
Italy	1891	Mannlicher-Carcano	Fixed vertical box	6	Clip	8.41	9.19
Japan	1907	Year '38 pattern	do	5	Charger	8.63	9.56
Russia	1894	"3-line" Nagant	do	5	do	8.95	9.70
United States	1903	Springfield	do	5	do	8.69	9.69
	1917	Enfield	do	5	do	8.87	9.87

Country	Length without bayonet, inches	Length with bayonet, inches	Length of barrel, inches	Diameter of bore, inch	Number of grooves in rifling	Depth of grooves, inch	Shape of groove	Twist of rifling, inches
Austria	50.00	59.50	30.12	0.315	4	0.0080	Concentric, beveled edge	9.842
Belgium	50.25	59.75	30.67	.301	4	.0065	Concentric	9.842
Canada [b]	52.00	58.80	28.00	.300	4	.0055	do	10.000
France	51.12	71.84	31.50	.315	4	.0059	do	9.450
				.315				
Germany	49.40	69.75	29.05	.311	4	.0065	Concentric	9.390
Great Britain	49.50	61.50	30.19	.303	5	.0065	do	10.000
	44.50	61.70	25.19	.303	5	.0058	do	10.000
Italy	50.75	62.38	30.75	.256	4	.0060	do	([d])
Japan	50.75	65.75	31.30	.256	4	.0060	Segmental	7.875
Russia	51.88	69.00	31.50	.300	4	.0070	Concentric, rounded edges	9.500
United States	43.21	59.21	24.01	.300	4	.0040	Concentric	10.000
	46.50	62.50	26.09	.300	4	.0040	do	10.000

[a] Sources of information: (1) Textbook of Small Arms, 1909, London. Printed for His Majesty's Stationery Office by Harrison & Sons, 250. (2) America's Munitions. (3) Training Regulations No. 320-10, War Department, Washington, Mar. 12, 1919.

[b] During the war the Ross was displaced by the British Enfield in the Canadian forces, principally to have all British forces armed with the same rifle. (Whelen, Townsend: The American Rifle; New York, The Century Co., 1918, 95.)

[c] See Figures 44 and 45 for further changes.

[d] Increasing from 19¼ to 8¼ inches.

ANTITANK RIFLE

During 1918, the Germans developed an antitank rifle. This was a single-shot 13-mm. rifle that had been developed pending the construction of a 13-mm. machine gun.[22] The weapon was very heavy, weighing 37 pounds, and was nearly 5½ feet in length, so it was necessary to provide it with a bipod for fixed position firing.[22] The bullet, weighing 570 gr., was pointed, and fired with an initial velocity of about 2,450 foot-seconds.[22] The bullet was of armor-piercing construction, and a penetration of 20 mm. of the best steel was claimed for it at a range of 500 yards.[22]

AUTOLOADING AUTOMATIC RIFLE

Besides those weapons listed in Table 4, a number of special rifles were developed and brought into military use for the first time during the war.[23] Of those which were designed to be fired from the shoulder the Mondragon, semiautomatic rifle, the St. Etienne semiautomatic rifle, and the Browning automatic rifle deserve mention.

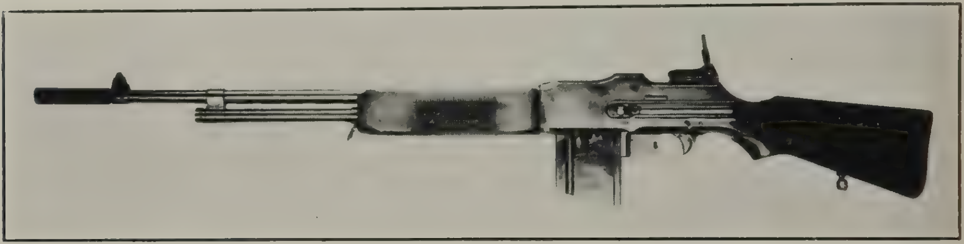

FIG. 51.—Browning automatic rifle, model 1918, caliber 30

The Mondragon semiautomatic, in use in the Mexican Army before the World War, was adopted by Germany in 1915, chiefly for aviators' use.[25] It was of 7-mm. caliber and provided with two types of magazines, one with a capacity of 10 rounds and the other with a capacity of 30 rounds.[25]

The French model, 1918, St. Etienne semiautomatic rifle, fired the Lebel 8-mm. cartridge. The magazine had a capacity of five cartridges.[23]

The American Army had about 5,000 Browning automatic rifles in use during the last two months of the war.[26] This gun, although handling the powerful 1906 United States rifle cartridge, had so slight a recoil that it could be fired continuously, without serious discomfort, at the rate of about 100 shots a minute.[22] The magazines held either 20 or 40 cartridges.[27]

MACHINE GUNS

Besides these autoloading automatic rifles designed to be fired from the shoulder, a number of automatic light machine guns were in use. The French used the Chauchat machine rifle,[28] model,1915. This gun,weighing 19 pounds and firing the ordinary 8-mm. Lebel cartridge, had a magazine which held 20 cartridges.[22] A bipod rest was attached to the fore end for fixed position firing. Hotchkiss light machine rifles firing the Lebel 8-mm. cartridge and weighing about 18½ pounds were also in use by the French Army.[22]

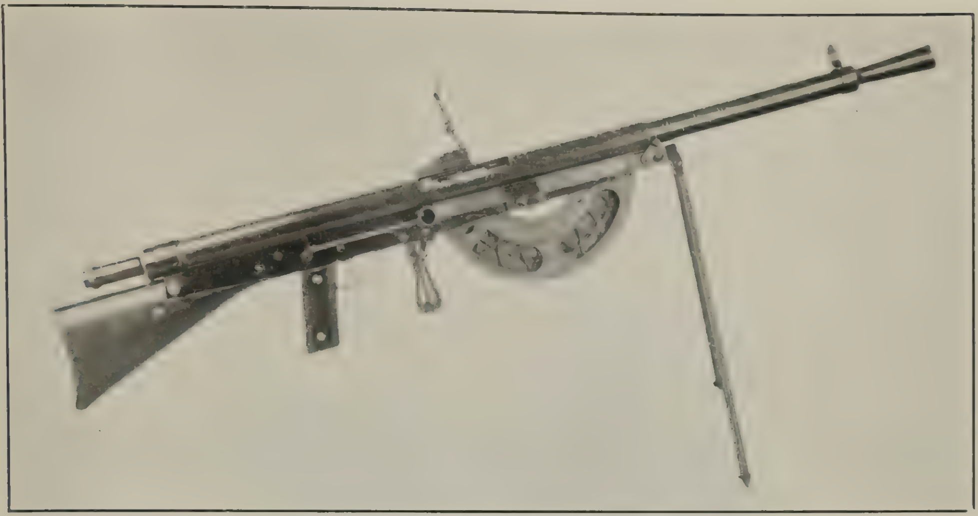

FIG. 52.—Chauchat machine rifle, model 1915, caliber 8 mm.

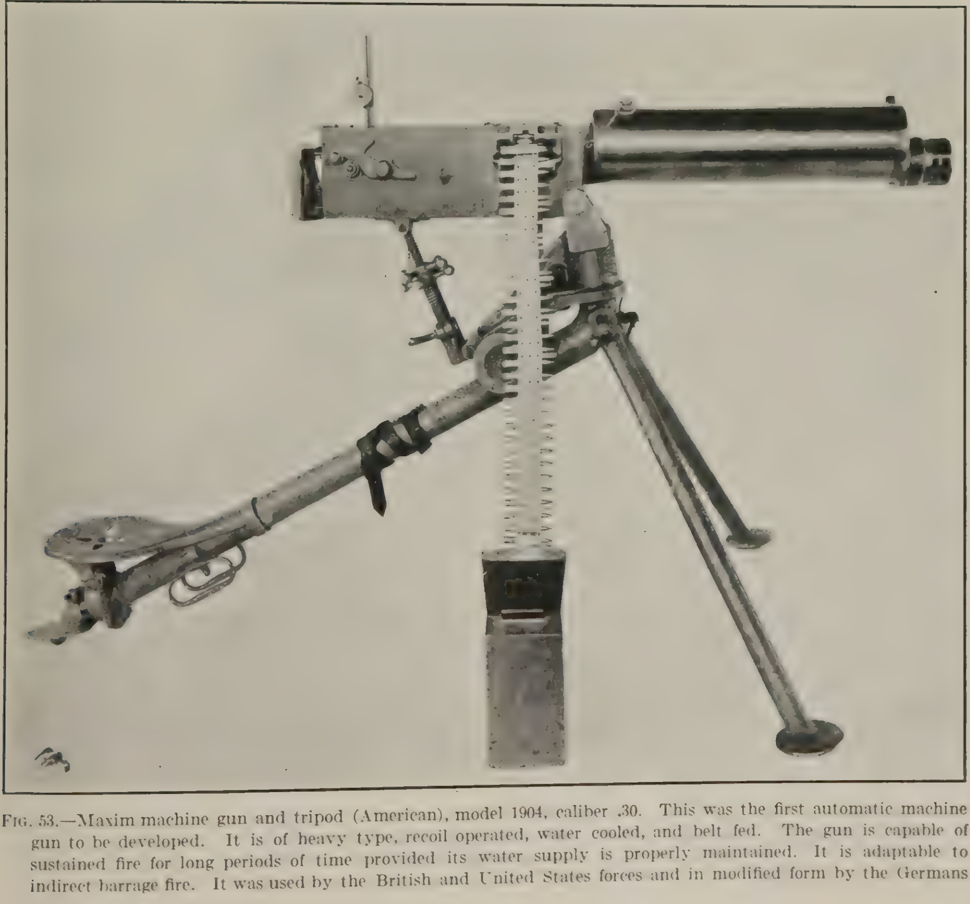

FIG. 53.—Maxim machine gun and tripod (American), model 1904, caliber .30. This was the first automatic machine gun to be developed. It is of heavy type, recoil operated, water cooled, and belt fed. The gun is capable of sustained fire for long periods of time provided its water supply is properly maintained. It is adaptable to indirect barrage fire. It was used by the British and United States forces and in modified form by the Germans

The Madsen machine rifle weighing about 16 pounds was used by the Russians.[22] The magazine held 40 rounds; when used as an automatic, the rate of fire was about 500 shots a minute.[22] The British Army used the light Lewis machine gun, which was of the "ground type," weighing about 26½ pounds.[22] In this type the magazine held 47 rounds of the ordinary 0.303 caliber rifle ammunition.[22] A somewhat heavier model, with the magazine holding 97 rounds, was used in aircraft by both the British and French.[22] These guns were capable of firing 600 shots a minute.[22]

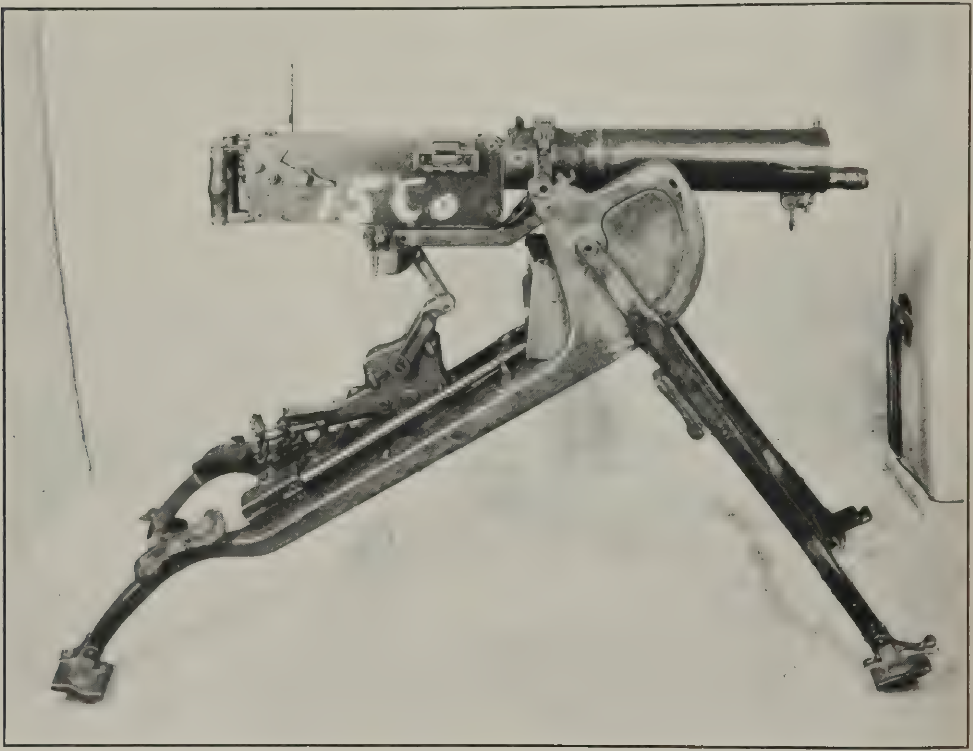

FIG. 54.—German Maxim machine gun on mount

The Germans used two types of light machine guns.[25] Early in the war the Bergmann, weighing 30 pounds, with a bipod mount, was much in use, although it was discontinued before the end of the war.[23] The principal light machine gun used by the Germans in the later years of the war was the Maxim 08–15.[25] This was a modification of the heavy Maxim machine gun with which the German Army was so abundantly supplied.[25]

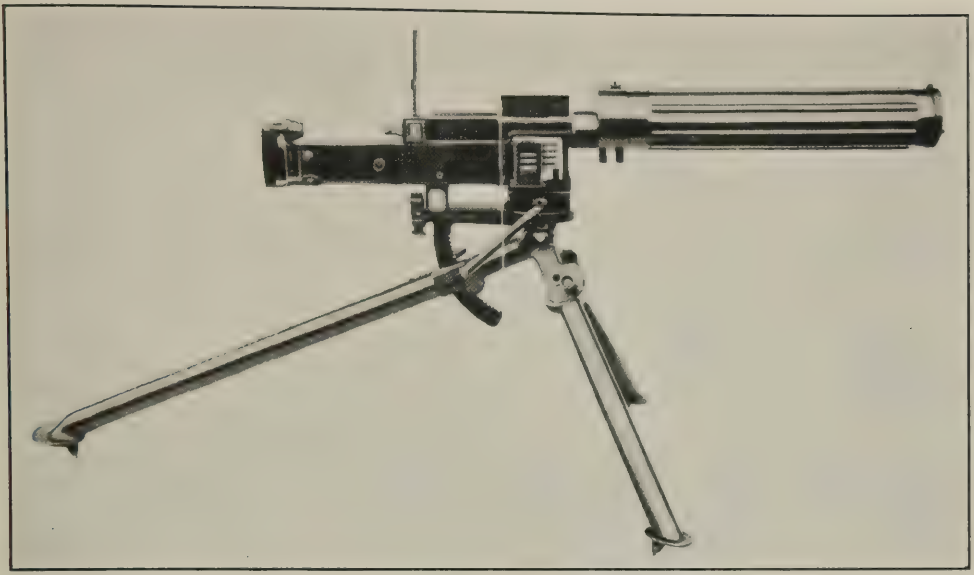

FIG. 55.—Fiat (Italian) machine gun and tripod

FIG. 56.—Browning heavy machine gun, model 1917

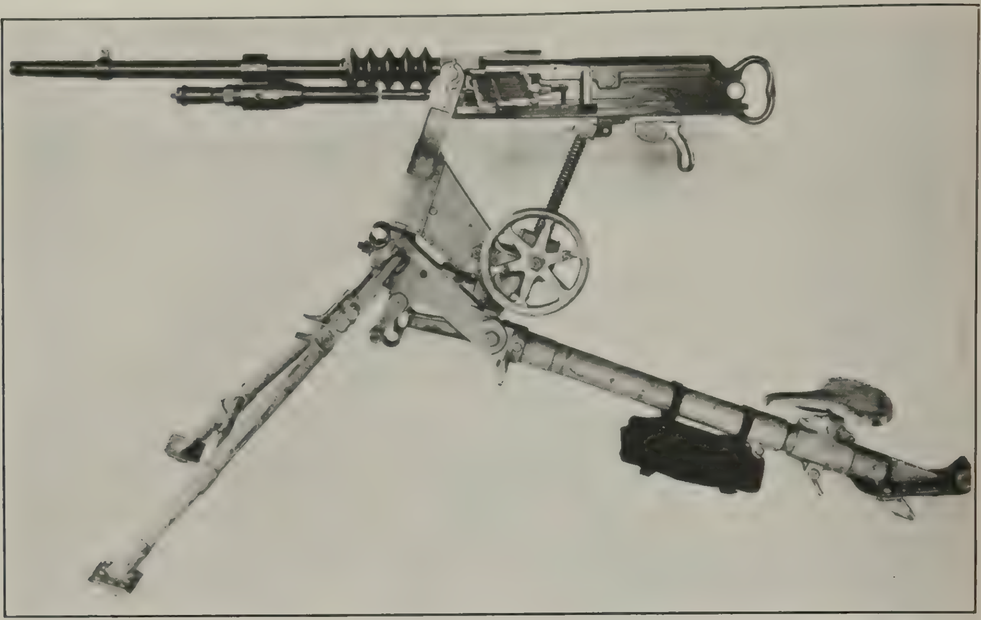

FIG. 57.—Hotchkiss machine gun, model 1914, 8-mm. This is the machine gun adopted by the French Army. It is of heavy type, air cooled, and gas operated. Its rate of fire is about 500 rounds per minute

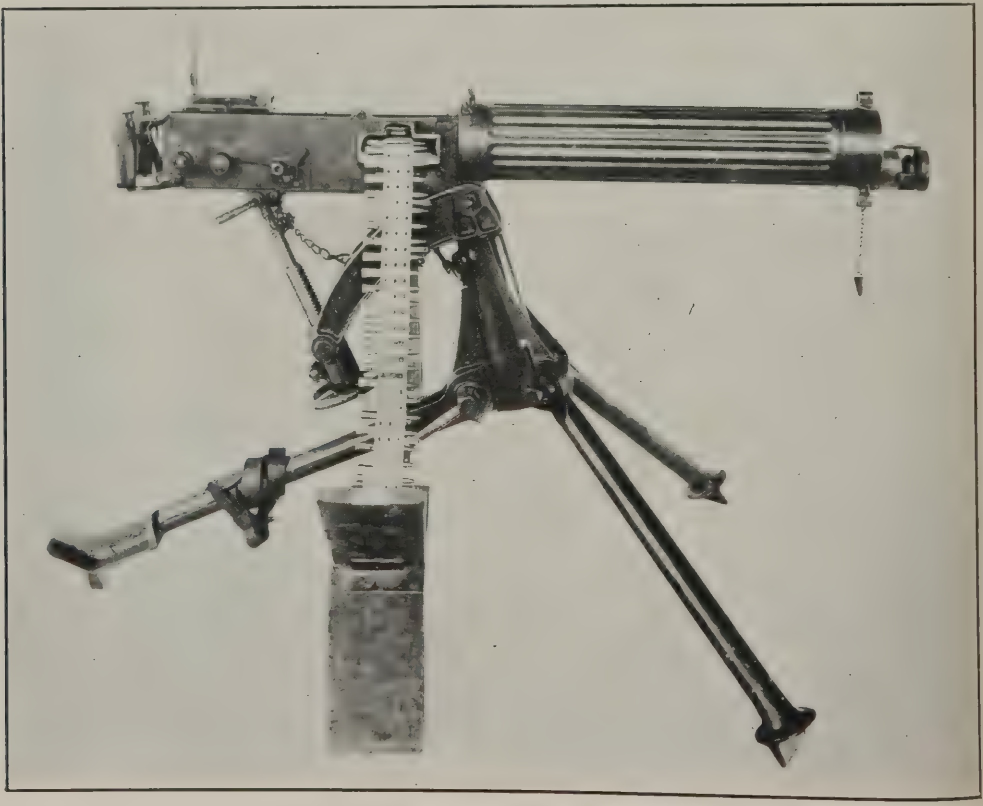

FIG. 58.—Vickers machine gun, model 1915, caliber .30

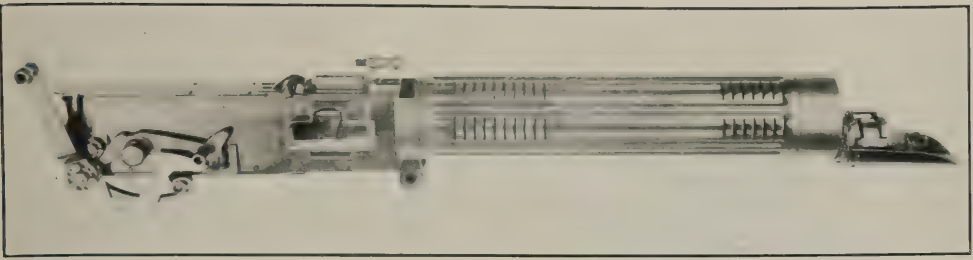

FIG. 59.—Vickers aircraft machine gun, model 1918, caliber .30

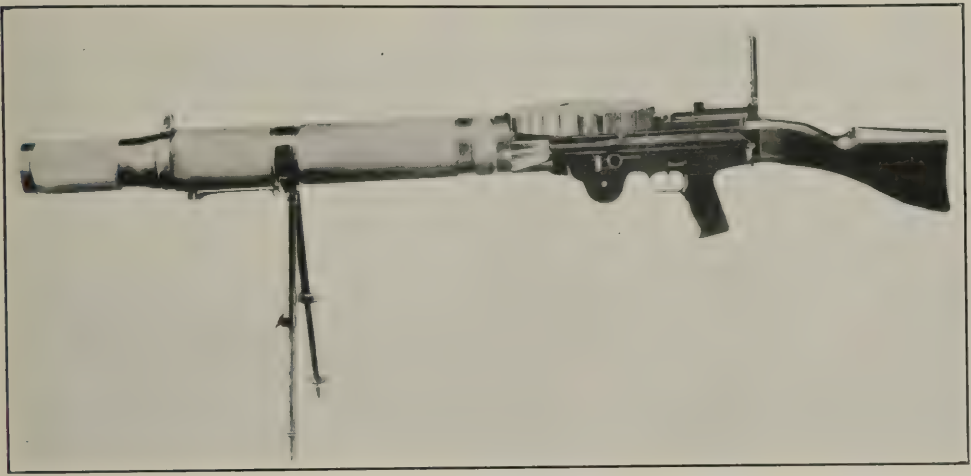

FIG. 60.—Lewis machine gun, model 1917, caliber .30, ground type

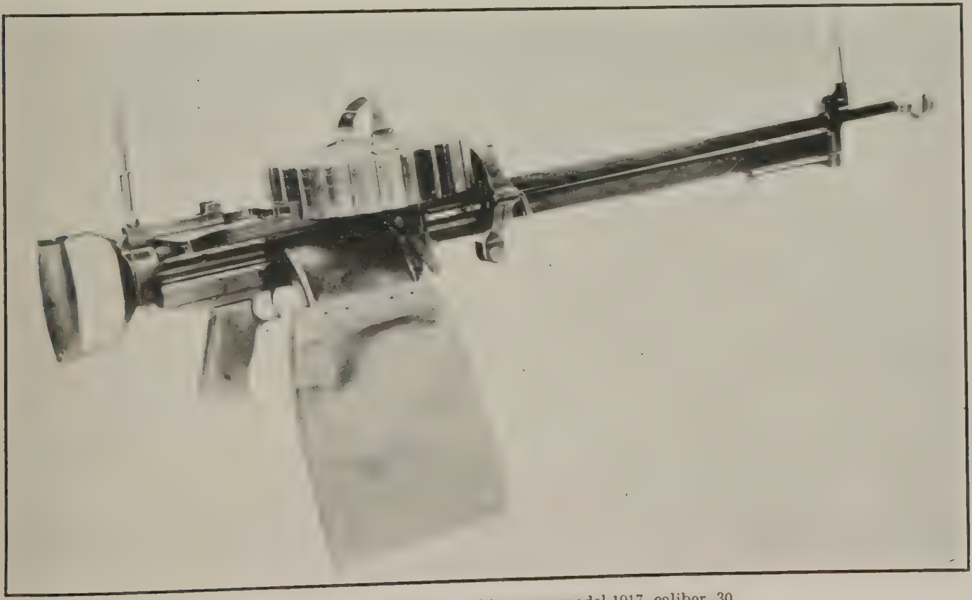

FIG. 61.—Lewis aircraft machine gun, model 1917, caliber .30

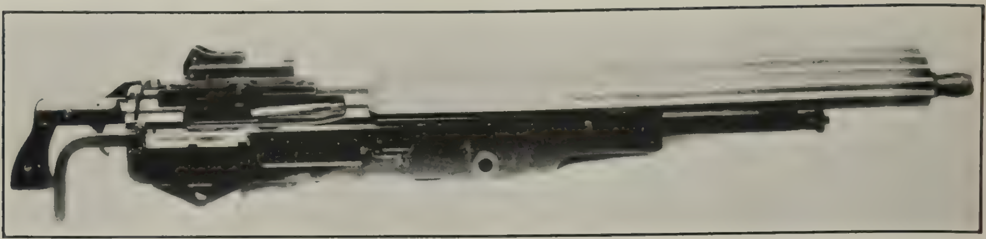

FIG. 62.—Marlin tank machine gun

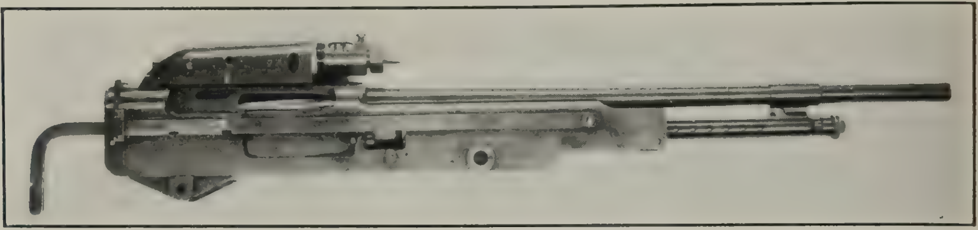

FIG. 63.—Marlin aircraft machine gun, type 8 M. G.

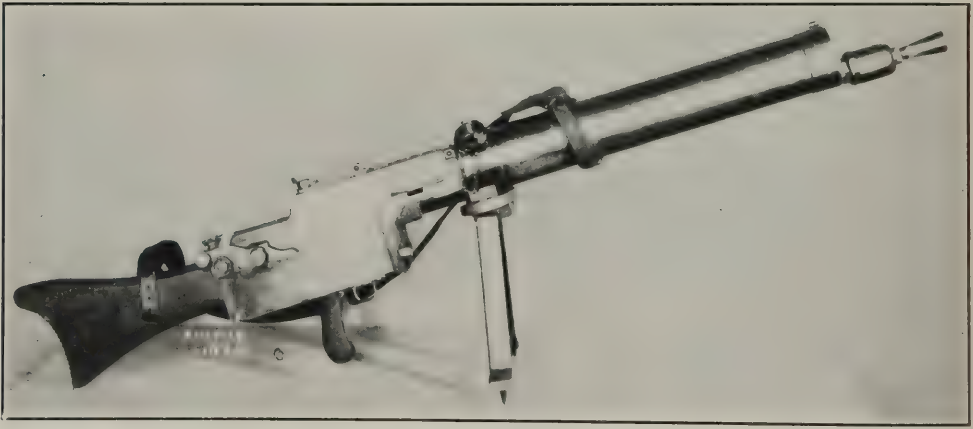

FIG. 64.—German 08/15 (Spandau) machine gun

MACHINE CARBINE PISTOLS

In 1918 the Germans brought into use a "snail" magazine holding 32 cartridges for the Luger service pistol, thus bringing this weapon into a class related to the light machine rifle.[29] This type of magazine, handling the 9-mm. cartridge, was used in the Luger with a long barrel and with a wooden buttstock attached to the hand grip as a shoulder piece.[29] When the gun was fired from the shoulder the magazine served as a fore-end, hip-elbow rest, thus giving unusual stability and accuracy to the very light weapon.[22]

The Bergmann pistol gun (officially pistol 18 I) which was in reality a carbine, fired the 9-mm. Luger pistol cartridge from a "snail" magazine holding 32 shots [29] at the rate of about 540 shots a minute.[22] This carbine was heavy, weighing about 9½ pounds without the magazine; it was sighted to 200 m.[22]

FIG. 65.—Colt .45 automatic pistol used by the American Army and, whenever obtainable, by other armies also

FIG. 66.—Colt double-action revolver, model 1917, caliber .45, with adapting clip to take rimless cartridges

FIG. 67.—Smith & Wesson double-action revolver, model 1917, caliber .45, with adapting clip to take rimless cartridges

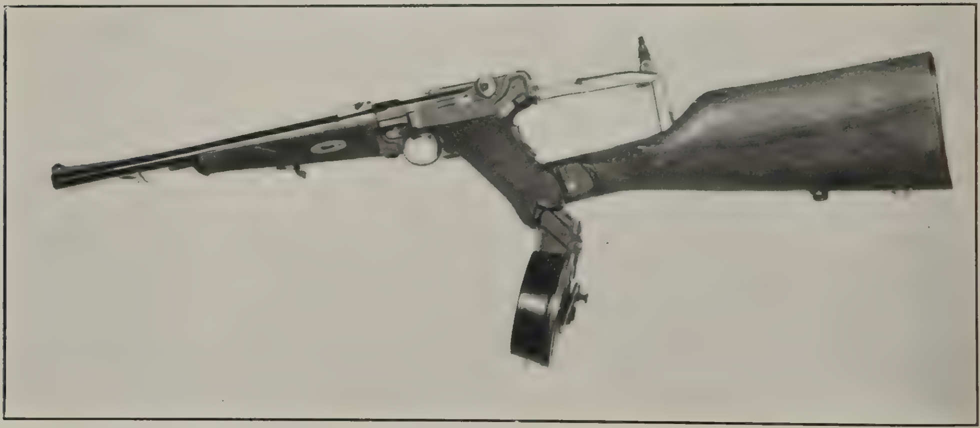

FIG. 68.—German Luger automatic pistol, caliber 7.65 mm. with "snail" magazine in place. The bridge from the receiver to the buttstock for mounting a Lyman sight is an American addition

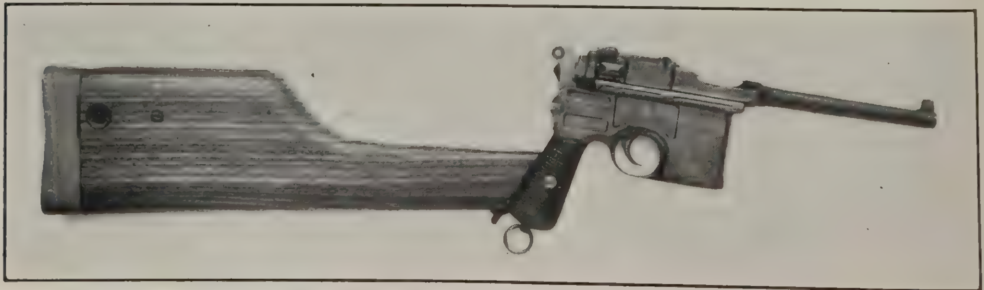

FIG. 69.—German Mauser automatic pistol, caliber 7.65 mm. The wooden buttstock is hollow and serves as a holster for the pistol

PISTOLS

The autoloading military pistol, with calibers ranging from 0.30 to 0.45 inch, was used in practically all combat branches of the service of all armies not armed with rifles.[30] Table 5 gives the principal ballistic factors of these autoloading pistols and their cartridges.

TABLE 5.—*Automatic pistols and their cartridges* [a]

Cartridge	Weight of bullet, in grains	Muzzle velocity, foot-seconds	Energy of bullet, foot-pounds
7.63-mm. Mauser	86	1,397	373
7.65-mm. Luger	93	1,173	284
0.32 automatic Colt, Webley, Scott, Browning, Bayard, Mauser, Clement, Stier	74	964	152
9-mm. Luger	125	1,039	300
0.38 automatic Colt, Bayard	130	1,146	379
0.380 Colt automatic, Savage, Webley, Browning 9-mm. (short), Remington, Bayard	95	887	116
0.45 Colt automatic, United States Government	230	809	335
0.445 Webley naval automatic	220	710	....

[a] Source of information: The Encyclopedia Brittanica, new volumes. XXXII, 107.

The German Luger (Parabellum) was the standard German side arm,[30] but owing to the great shortage of these weapons as many as 28 different models of pistols and revolvers were in use in the Germany Army.[31] The Colt automatic pistol, caliber 0.45, was in use by the American Army.[32] The regular magazine held seven cartridges. It proved to be the most effective side arm in use during the war; however, because it could not be produced in sufficient number to arm completely the American forces, Colt and Smith & Wesson revolvers of 0.45 caliber were adapted to use the rimless cartridge of the Colt pistol.[32] They were as reliable, accurate, and effective as the pistol, but of course slower in functioning.

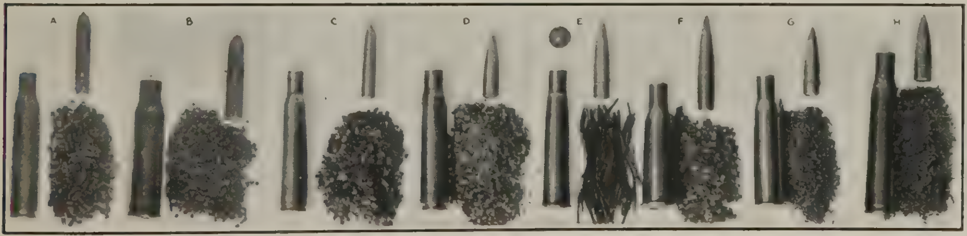

FIG. 70.—Photographs of various dissected rifle cartridges. A. Italian Mannlicher (Carcano) (6.5 mm.); B. Austrian Mannlicher (8 mm.); C. German (Mondragon (7 mm.); D. German Mauser (8 mm.); E. British Lee-Enfield (.303 in.); F. French Lebel (8 mm.); G. Russian Nagant (.300 in.); H. U. S. .06 (.300 in.)

SMALL-ARMS MISSILES

RIFLE MISSILES

In Table 6, data are given concerning various rifle missiles. It will be noted that, with the exception of the Italian and Japanese rifle cartridges, the bullets of the others were practically 0.3 of an inch in diameter (30 caliber, or 8 mm.); also, with the exception of the Austrian, the bullets were of approximately the same weight, namely, from 150 to 198 gr. Likewise, their initial velocity did not vary greatly, running from 2,121 feet a second to 2,866 feet

a second. The initial muzzle energies of translation were also fairly close, being, except the Italian, from 2,216 to 2,685 foot-pounds.

TABLE 6.—*Various dissected rifle cartridges and their ballistic data* [a]

Country	Rifle		Powder		Bullet			Muzzle velocity	Muzzle energy
	Kind	Caliber	Weight	Type	Length	Diameter	Weight		
			Grains		*Inches*	*Inch*	*Grains*	*Foot-seconds*	*Foot-pounds*
Austria	Mannlicher	[b] .315	43	Nitrocellulose	1.25	0.323	241	2,121	2,408
France	Lebel	[b] .315	46	do	1.54	.320	198	2,270	2,266
Germany	Mauser	[b] .311	48	do	1.10	.323	154	2,777	2,637
Great Britain	Lee-Enfield	.303	38	Nitroglycerine (cordite).	1.3	.311	174	2,440	2,300
Italy	Mannlicher-Carcano.	[c] .256	35	Nitroglycerine (ballastic).	1.25	.266	161	2,265	1,857
Russia	Nagant	.30	48-50	Pyroxilin	1.12	.308	149	2,866	2,685
United States	Springfield, 1903. (1906 cartridges).	.30	47-50	Pyrocellulose	1.07	.308	150	2,700	2,429

[a] Sources of information: (1) Table RN 471.842/45. On file, Infantry and Aircraft Armament Division, Manufacturing Service, Ordnance Department, unnumbered. (2) Table, Ballistic information and results of firing ammunition of the various countries. Fired at the experimental station. Ballistics Division, experimental station, E. I. Du Pont de Nemours & Co., Henry Clay, Delaware. On file, Infantry and Aircraft Armament Division, Manufacturing Service, Ordnance Bureau, unnumbered. (3) Textbook of Small Arms, 1909, printed for His Majesty's Stationery Office. London, Harrison & Sons, 250. (4) Consolidated Data of Reports on Hand at Frankford Arsenal, Pa., British Small Arms Ammunition, May, 1920; source unknown. On file, Infantry and Aircraft Armament Division, Manufacturing Service, Ordnance Bureau, unnumbered. (5) Report on French Small Arms Ammunition, Frankford Arsenal, Pa., March, 1920, by W. L. Clay, lieutenant colonel, Ordnance Department, U. S. Army. On file, Infantry and Aircraft Armament Division, Manufacturing Service, Ordnance Bureau, unnumbered. (6) Collection of Reports on German Small Arms Ammunition, Frankford Arsenal, Pa., July 18, 1919, by W. L. Clay, lieutenant colonel, Ordnance Department, U. S. Army, commanding. On file, Infantry and Aircraft Armament Division, Manufacturing Service, Ordnance Bureau, unnumbered. (7) Training Regulations No. 320-10, W. D., Washington, March 12, 1924. (8) Handbook of Ordnance Data, Nov. 15, 1918. Washington, Government Printing Office, 1919. (9) History of the Great War Based on Official Documents, Medical Services, Surgery of the War, London, His Majesty's Stationery Office, 1922, I. 7.
[b] Eight millimeters.
[c] Six and a half millimeters.

While all of these bullets possessed sufficient energy to be mankilling in the limits of all ranges at which they could be purposively directed, yet their shape, composition, and maintained energy varied so greatly as to produce widely different effects. It is therefore necessary to analyze each cartridge in detail.

The .30-caliber United States Springfield bullet as fired from the 1906 model cartridge during the war weighed 150 gr.[33] It was composed of a solid lead core surrounded by a cupro-nickel jacket of very high tensile strength. Its remaining velocity at 500-yard range was 1,668 foot-seconds and its remaining energy 932 foot-pounds.[34] At the 1,000-yard range its remaining velocity was 1,068 foot-seconds and its remaining energy 382 foot-pounds.[34] At the 1,500-yard range its remaining velocity was 853 foot-seconds and its remaining energy was 244 foot-pounds.[34]

The bullet of the .303-caliber British Lee-Enfield cartridge left the muzzle of the gun with 2,440 foot-seconds velocity and a muzzle energy of 2,300 foot-pounds.[35] This bullet, however, weighed 174 gr.[35] and therefore maintained its velocity and energy better than the lighter Springfield bullet. Its extreme effective ranges were practically the same as those of the Springfield. The base and body of the core of the bullet was composed of solid lead, but the point consisted of a small cap of lighter material, either aluminum or stalbite (hardened paper pulp).[36]

The bullet of the Russian cartridge, as made in America, was practically identical with that of the Springfield bullet, and had practically the same muzzle velocity and muzzle energy.

The bullet from the 8-mm. German Mauser cartridge weighed a trifle more than the Springfield bullet. It possessed about 200 foot-seconds more muzzle velocity and 200 foot-pounds more muzzle energy. Its range was longer and its maintained energy slightly higher at long ranges than that of the Springfield bullet. The core was of solid lead, the jacket of low carbon steel, nickel or copper plated.[35]

The French 8-mm. bullet was nearly one-third heavier and one-third longer than the Springfield bullet. Its muzzle velocity was much less than that of the Springfield, and its muzzle energy considerably less. Its maintained energies were greater at extreme ranges than those of the Springfield bullet.[22] This was due not only to its superior weight but also much to its superior shape. The bullet was reduced in diameter from 0.320 inch at its middle to 0.270 inch at its base; its forward part (shoulder) was very sloping. Owing to these factors it encountered less resistance to the air than did any other military bullet. The French bullet was of solid bronze, containing neither core nor jacket to separate or split.[7] Because of these factors when flying head-on this bullet produced clean-cut wounds.[7]

The Austrian Mannlicher rifle, model 1895, fired a bullet 0.323 inch in diameter (8 mm.) and 1.25 inches in length, weighing 241 gr., with a muzzle velocity of about 2,121 foot-seconds. Because of its relatively heavy weight, this bullet had a relatively high muzzle energy. However, since it had an ogival head, rather than a pointed one, the resistance of the air to its passage was relatively high,[37] and its velocity and energy were both rapidly reduced. This bullet consisted of a solid lead core with a low carbon steel envelope similar to that of the German Mauser bullet.[37]

The Italian Mannlicher-Carcano rifle, 1891 model, fired a bullet 0.267 inch in diameter (6.5 mm.), 1.2 inches long, and weighing 162 gr. It had a velocity of about 2,400 foot-seconds and approximately 2,000 foot-pounds muzzle energy. The bullet consisted of a lead core surrounded by a cupro-nickel envelope.[37] This bullet had an ogival head with consequently high air resistance which caused it to fall off rapidly in velocity and energy.[37]

SPECIAL RIFLE BULLETS

Besides rifle bullets referred to above, various special bullets for small arms (rifle and machine guns) were made. Practically all of these may be classified as armor-piercing, tracer, incendiary, wire-cutting, or explosive.

Armor-piercing small-arms bullets consisted essentially of a hard steel core surrounded by a jacket composed of cupro-nickel alone or of a thin coating of lead covered with a cupro-nickel jacket of ordinary thickness.[38] Bullets of this type not previously mutiliated by striking armor or other metal objects were likely to penetrate the human body, including bones, without deformation. On coming in contact with even fairly thick steel armor the relatively soft cupro-nickel jacket was split, permitting the passage of the steel core through the metal.[38] These bullets were used by the Germans, chiefly against tanks and occasionally against armored adversary machine-gun operatives and airplanes.[39]

Tracer bullets contained in a small cavity in the base a slow-burning compound which produced smoke, or more often a small speck of bright light visible even in the daytime.[40] The forward part of the bullet consisted of a lead core and the whole was encased in a cupro-nickel or low-carbon steel jacket.[40] During the later stages of the war the Germans devised an armor-piercing tracer bullet.[39] However, in this the steel core was rather too small to be very effective. Tracer bullets were used almost entirely by airplanes.[40]

Fig. 71.—German antitank rifle cartridge, compared with the United States Springfield model 1906 cartridge. Full size

Incendiary bullets contained, within a chamber in the fore end, phosphorus, access to which was provided by a hole drilled on one side of the missile through the jacket and the lead core of the base.[40] The passage of the bullet through the gun barrel melted the solder with which the hole was closed and ignited the phosphorus within the chamber.[40] The rotation of the bullet whirled the burning phosphorus out through the open hole.[40] This bullet had an effective range of about 350 yards, beyond which the flame was extinguished.[40] The smoke from the burning phosphorus served to make this bullet also of tracer character.[40] These tracer incendiary bullets were produced by the French and the Americans in 11 mm.,[41] as well as in the ordinary 8 mm. and .30 caliber. The flame from these large caliber bullets continued up to 1,200 yards range.[42]

Numerous attempts were made to improve the wire-cutting qualities of rifle and machine-gun bullets, either by cutting off the head of the ordinary pointed bullet with wire clippers or other wise mutilating them.[43] These efforts were not successful. The Germans developed a cylindrical steel bullet for the same purpose, but it also was not satisfactory.[43]

An explosive rifle bullet was made by the Germans which contained at the point within cupro-nickel and lead jackets a complicated firing mechanism consisting of a percussion cap, a suspension coil spring, and a striker.[43] This mechanism was contained within a brass collar and was designed to explode a relatively large compressed bursting charge in the rear of the bullet to which the flame from the cap gained access by way of a channel through a brass

container in the middle portion of the bullet.[43] This container was filled with a composition of potassium chloride and antimony sulphide.[43] Experiments by the Allies with captured bullets of this variety showed that they had considerable penetrative power before explosion and that they must have been designed for their explosive effects only, since they were valueless as tracers or for incendiary purposes,[43] although the Germans stated that they were intended for ranging purposes.[39]

In the early years of the war many accusations were made by each of the warring nations that the enemy was using explosive and "dum-dum" bullets.[36] While any bullet might be made into "dum-dum" pattern by mutilating its forward end in any way, the only "dum-dum" "mushrooming" bullets which had evidently been manufactured in soft-point form which came under the writer's observation were those in cartridges removed from the pockets of a German sharpshooter in the Chateau-Thierry operation.[36] These were American-made 0.256 Newton (6.5 mm.) bullets with soft-lead points, each with a small steel tack embedded therein. They were of pre-war manufacture (about 1912),[36] loaded in German-made cartridge cases which had evidently been necked down from the ordinary 8-mm. size, and were being fired from a Mauser rifle of 6.5-mm. caliber. They probably represented a personal experiment of the sharpshooter on whose body they were found.

The fact that "explosive," "dum-dum," and "mutilated" bullets were not more frequently used was probably due more to the difficulties of their manufacture, their inaccuracy, and their ineffectiveness. The ordinary bullets from rifle and machine gun were found to be sufficiently effective to satisfy military necessity.

PISTOL BULLETS

TABLE 7.—*Various dissected pistol cartridges and their ballistic data* [a]

	A	B	C	D
	.38 Colt automatic pistol	.45 Colt automatic pistol. U. S. Government	.30 (7.63-mm.) Mauser automatic pistol	.30 (7.65-mm.) Luger automatic pistol
Powder, grains	[b] 4.5	[b] 5	[c] 7.5	[c] 5
Bullet:				
Length, inches	.56	.66	.56	.56
Diameter, inches	.358	.450	.300	.308
Weight, grams	130	230	86	93
Muzzle velocity, foot-seconds	1,146	802	1,397	1,173
Muzzle energy, foot-pounds	379	329	373	284

[a] Sources of information: (1) Table, Ballistic information and results of firing ammunition of the various countries. Ballistic Division, experimental station, E. I. Du Pont de Nemours & Co., Henry Clay, Del., Dec. 16, 1919. On file, Infantry and Aircraft Armament Division, manufacturing service, Ordnance Bureau, unnumbered. (2) The Encyclopedia Britannica, 1922, xxvii, 107. (3) Training Regulations, No. 320-15, W. D., Washington, March 3, 1924, 5.
[b] Bull's-eye.
[c] Flake.

Figure 72 and Table 7 show the shell, powder, and bullet, together with the ballistic data of several of the more important cartridges used in automatic pistols during the World War.

The bullet fired by the .45 Colt automatic pistol was the heaviest used except that of the Webley automatic pistol in use in the British Navy. The Colt bullet weighed 230 grains and had a muzzle velocity of 802 foot-seconds and a muzzle

energy of 329 foot-pounds.[44] Because of their heavy weight and large cross section this bullet and that of the .45 Webley possessed greater man-stopping power than that of any other bullet used in pistols.[45]

The bullet of the .38 Colt and Bayard automatic pistols weighed 130 grains and was fired with a muzzle velocity of 1,146 foot-seconds and a muzzle energy of 379 foot-pounds.[31] At close quarters this bullet was more likely to pass through the body than was the .45 Colt. Thus, although it possessed more muzzle energy than the .45,[31] it did not have as much man-stopping power.[46]

The bullet of the .30 Luger automatic pistol (7.65 mm.) weighed 93 grains and was fired with a muzzle velocity of 1,173 foot-seconds and a muzzle energy of 284 foot-pounds.[31] Its head was a truncated cone which served to reduce the air resistance to it but also reduced its man-stopping power.[46]

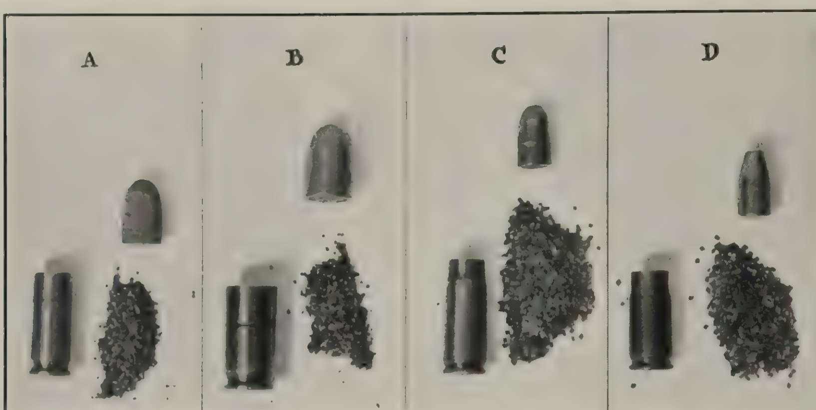

FIG. 72.—Photographs of sundry dissected automatic pistol cartridges. A. .38 Colt; B. .45 Colt; C. .30 (7.63 mm.) Mauser; D. .30 (7.65 mm.) Luger

The bullet of the .30 Mauser automatic pistol (7.63 mm.) weighed 86 grains and was fired with a muzzle velocity of 1,397 foot-seconds and a muzzle energy of 373 foot-pounds.[31] This bullet had an ogival head similar to that of the .45 and .38 Colt bullets.[31] Its velocity and energy were well retained at relatively long ranges, but its small caliber and relatively high velocity contributed to reduce its man-stopping power.[46]

As a whole the experience of the World War bore out the previous experience of the United States Army in the Philippines, that a pistol bullet of large size (.45 caliber), heavy weight (230 grains), and relatively low velocity was much more effective as a "man stopper" at close quarters than any other yet devised of smaller caliber.[47]

BOAT-TAIL BULLETS

The most recent development of rifle bullet designing has been in so modifying the base of the missile as to reduce the negative pressure set up by its passage through the air.[48] Double-pointed bullets of all sorts have been experimented with, but, in general, nations now are apparently settling down to the so-called "boat" shape; that is, with a long pointed front, a cylindrical center, and a base which is a truncated cone. This boat-shaped bullet, first tried out by the French and later perfected by the Swiss, was adopted early

in the war by the French, and later by the British, Germans, and Americans.[49] Properly designed these bullets are said to have less than one-half the resistance to the air that is offered by missiles with ogival heads of 1½ diameters.[50]

GENERAL CHARACTER OF WOUNDS FROM VARIOUS CAUSATIVE AGENTS

Relatively large, smooth missiles of low velocity, such as shrapnel balls near the end of their flight, produce wounds of little depth, with but slight tearing, and with considerable contusion of the tissues. Large missiles of irregular shape and low velocity, such as large shell fragments near the end of their flight, produce ragged wounds with considerable bruising and little penetration. Large or small missiles of very high velocity, such as fragments from high-explosive shells in the first portion of their flight, and modern rifle missiles in the first mile of range, produce "explosive" wounds, with the wound of exit larger than the wound of entrance. Shape and velocity remaining the same, doubling the weight of the missile doubles its wounding power. Shape and weight remaining the same, doubling the velocity quadruples its wounding power, since it quadruples its energy. When weight and velocity remain the same, increase in sectional area either regularly or irregularly, as in a bullet with flattened point or one with the deformity of a split jacket, produces additional wounding capacity, and especially its "shock" effect, which can not be stated mathematically since it will vary so greatly with the character of the tissue affected.

With these general principles in mind, though all of them are subject to innumerable modifications, some general conception of the types of the wounds produced from various missiles may more readily be understood. The effects of shrapnel bullets and shell fragments from the older types of explosive missiles have been so well described by LaGarde,[51] Stevenson,[52] and others that there is no need of repeating them here. It was supposed that the very greatly increased velocity and the very much greater comminution of shell fragments, due to the use of much higher explosives in the shells during the recent war, would eliminate in large measure the type of wound from shrapnel and shell fragments so common in previous wars. This has not proved to be the case. Very many wounds from shrapnel ball and shell fragments were of the old type, namely, with slight penetration, much contusion, and incidentally much infection with foreign matter. A large number of the shrapnel and shell-fragment wounds among the American Expeditionary Forces must have been produced by relatively low velocity missiles. This explains why the surgeons with the American Expeditionary Forces so seldom stated the causative agent as from high-explosive shell.[53]

On the other hand, in close quarters, as in trench fighting, where men were struck by missiles from exploding bombs and grenades, the character of the wounds often indicated that the missiles were of relatively high velocity.

In general it may be said that shell fragments and shrapnel bullets, whatever their primary velocity, rapidly become slow and depend less for their wounding effect on velocity than on their weight and shape.[54] Thus they have but small power of penetration and frequently lodge in the body. They are likely to carry clothing and other foreign matter into the wound. On the other

hand, rifle missiles and secondary missiles of all kinds from high-explosive charges, striking the body while still having a high velocity, produce effects from their kinetic energy in penetration, "explosive" exits and injury at relatively large distances from the tract of the missile, which are quite different from all low-velocity missiles; also they are less likely to carry foreign matter into the wound.

WOUNDS FROM EXPLOSIVE MISSILES

Sufficient has been said above to indicate to the surgeon the very great variety, both in extent and character, of the effects on human tissue of shrapnel and shell fragments from exploding artillery missiles. Occasionally steel shell splinters of needlelike fineness were hurled with such tremendous velocity that striking end-on they penetrated the body wall either from the back, the front, or the sides and caused ultimately fatal hemorrhages by injuring large arteries, or the heart itself. In some instances the wound of entrance of these missiles was almost imperceptible. On the other hand, large masses of metal, weighing as much as 2 or 3 pounds, had frequently so little remaining velocity when they struck the body that they did not rupture the skin or at most barely buried themselves in the flesh. It was surprising, however, what large masses of metal were found occasionally lodged in the human body. Between these two extremes of light weight with high velocity and heavy weight with low velocity every conceivable variety of weight and velocity of missile existed and likewise every conceivable variety of wound effects.

If the missile lodged in the body, study of its shape and size, together with consideration of the tissues met with, gave some indication of its remaining velocity at the point of entrance. If the wounding missile had passed out of the body, unless both wound of entrance and wound of exit were small, it was impossible even to estimate the ballistic data. To these uncertainties was added the possibility that the wound might not have been produced by artillery fire but by a rifle or machine-gun bullet of unusual shape or flight, a subject which will be discussed below.

WOUND PRODUCTION BY SMALL-ARMS MISSILES

The World War afforded uprecedented opportunity to study the effects of high-velocity rifle bullets in human wound production. Leaving aside for the moment the unusual wound effects produced by deformed bullets and by bullets of irregular flight, the causes and effects of which have already been hinted at in the preceding analysis of the various types of bullets, we may examine the causes of the wound conditions produced by the normal-shaped bullet which struck human tissues while it was in normal flight.

The wounding effects of a bullet depend on (*a*) the amount of energy it transmits to the tissues, (*b*) the velocity of the transmission, (*c*) the direction of the transmitted energy, and (*d*) the density of the tissues. The first three of these factors depend almost entirely on the energy, velocity, and shape of the bullet.

All rifle bullets used in the World War were several (three to five) times longer than they were thick. (See Table 6.) All except the Austrian and Italian

had very sharp-pointed forward ends and cylindrical bodies. Their surfaces were smooth except for the spiral longitudinal grooves, about 0.004 inch deep, cut by the lands of the rifle barrel through which they were fired. They left the gun muzzle with a velocity usually somewhat more than twice that of the velocity of sound (from 2,200 to 2,800 feet a second) and they were rotating on their long axes in most instances more than 3,000 times a second, with a surface speed of about 260 feet a second. The muzzle energy of their forward motion (translation) was about 2,400 foot-pounds and that of their motion of rotation was about one two-hundredths as much, or 12 foot-pounds. The different bullets used varied greatly in the rates in which their velocities of translation were reduced. The rate of reduction of the velocity of rotation is almost

FIG. 73.—Various deformed rifle bullets removed from wounds

impossible of calculation, but it is not as great as the rate of reduction of velocity of translation, since we know that a bullet will continue to spin after it has ceased to move forward.

The amount of energy transmitted to the animal body by a bullet is the amount with which the bullet enters less that with which it leaves the body. If the bullet does not pass out of the body it transmits to it all of its energy. If it does pass out, it obviously does not transmit to the body the energy it retains after exit. The proportion of energy transmitted depends on the sectional area of the bullet, the shape of its head, the character of its surface, and the relative densities of the tissues struck. This is why a blunt-pointed, large-caliber revolver bullet, like the Colt .45, lodging in the body, may cause more tissue destruction and more shock than a sharp-pointed small caliber

bullet carrying much more energy but passing through and out of fleshy structures with but slight loss of energy.

When the modern high-velocity, sharp-pointed military rifle bullet enters the human body it may produce terrific destruction of tissue at very considerable distance from its line of passage. It may do this without being in any way deformed in shape or flying erratically. The cause of the so-called explosive effects of the modern rifle bullet has been the subject of prolonged discussion and experimentation by many careful students. It can not be said that the solution of the problem is yet entirely clear. However, from long experimentation and consideration of the laws of physics the following consideration derived from observations of wounds in man and animals would appear to be of most weight in the explanation of the phenomena:

When the sharp-pointed rifle bullet enters the body point-on and passes through it without tumbling, its wound production is the result of the transmission of energy from the bullet's two motions, first, of translation, and second, of rotation. If the bullet were a cylinder it would act much like a punch, but though the body of the bullet is a cylinder the forward end has long, sloping shoulders which act as wedges. As a consequence of this, the energy of the bullet is transmitted not directly forward but at oblique angles with that of the path of the bullet. The energy is thus transmitted through an area of tissue which is represented roughly by a broad-base cone having its apex at the point of entrance and its base surrounding the point of exit. Besides the motion of translation, a small amount of force is no doubt exerted by the motion of rotation. The energy of the bullet from its motion of rotation is transmitted centrifugally at right angles to the track of the missile. It is probable that the energy of rotation is reduced less in proportion than the energy of translation by the passage of the bullet through the tissues; thus the energy of rotation of the bullet may be a relatively greater factor in the resultants representing the total transmitted energy of the bullet at the exit than at the entrance point.

This transmission to the tissue of the energy of the bullet at decided angles to its path explains the dissemination of foreign bodies, and incidentally bacteria along with them, to points in the tissues at considerable distances from the path of the projectile. Dense particles, as, for example, charcoal used experimentally on the skin at the point of entrance of the bullet, are not driven into the tissues but are scattered widely through the tissues along the track of the missile. This is a most important point for the surgeon to remember in his primary treatment of wounds made by high-velocity bullets.

But the physics of dense particles driven through soft tissues will not explain the phenomena encountered in "explosive" wounds of soft tissues. When the particles of a plastic body are set in motion by being struck by a missile the distance to which the motion is transmitted is determined by the freedom with which the particles move. Experimentally the energy of a high-velocity rifle bullet is transmitted approximately four times as far in 5 per cent gelatin as in 10 per cent gelatin and approximately nine times as far in 5 per cent gelatin as in 15 per cent gelatin. In other words, in plastic bodies the *distance* to which the energy is transmitted by a rapidly moving bullet is approximately

inversely proportional to the squares of the densities of the masses penetrated.[36] On the other hand, the *velocity* with which tissues of greatly differing densities move when set in motion by transmitted bullet energy is apparently, though roughly, in direct proportion to their densities, and may result in shattered parts of a more dense tissue, as bone, being driven through a less dense tissue, as muscle. Apparently when tissues approximate each other in densities, none of which are sufficiently great to permit of angular fragmentation, as, for example, the several coats of the wall of an artery, particles of the one are not driven through the other by transmitted bullet energy. Probably both are moved but at somewhat different velocities. It may be assumed that these different velocities may produce unequal stresses. This possibly may be the cause of the frequently observed ruptures of the intima of large arteries by the passage near, but not in contact with them, of high velocity bullets.

On the whole, then, it seems reasonable to assume that the "explosive" effects produced by high velocity rifle bullets, either experimentally or in war wounds, in their passage through liquid or plastic substances may be due to the angular and lateral transmission of the energy of the bullet to the mass as a whole, thus setting up violent motion in the particles of the mass which are transmitted throughout the whole mass from particle to particle. In homogeneous fluids and plastic structures of low density all particles move together wavelike. In composite tissues of varying densities irregular stresses are developed which tear or even comminute the tissues.

IRREGULAR MOVEMENTS OF BULLETS IN TISSUES

There is a great tendency for the modern pointed bullet to tip on striking tissue of any considerable density. This is most noticeable, of course, with bullets of reduced velocity. These sometimes follow most eccentric paths in the body. Not infrequently they follow the curve of a rib for considerable distance without puncturing it.

The amount of actual tumbling within the body which a bullet is capable of making is a question of considerable dispute. It is doubtful, however, if any bullet turns completely over more than once or twice in passing through the human body. Of course, even this amount of tumbling would transmit an enormously increased amount of energy to the tissues.

At all except extreme ranges the straight-flying modern military bullet should pass completely through the human body. However, a great many bullets fired at comparatively short ranges were known to have remained in the body. It is probable that some bullets remaining in the body after wounding at short range may have previously encountered other obstacles which reduced their energy. Others may have been fired from worn-out rifle barrels.

SITE AND CHARACTER OF INJURY IN THE BATTLE DEAD

The military surgeon is concerned only with the wounded soldier. The military pathologist is concerned also with the dead soldier; the site and character of injury of men killed in action involve problems in which the military pathologist is much concerned.

The number of men killed in action constitutes a very appreciable share of the total casualties. Prior to the World War, it was generally accepted that the ratio of those killed or found dead on the field to the number wounded was 1 to 4.[55] This ratio, of course, is very much influenced by the mode of attack. In the American Army during the World War, this ratio was slightly less. The total number killed or missing on battle fields in the American Expeditionary Forces was 36,780.[56] The total number of wounded was 153,537,[53] comprising only those wounded by military destructive agents, excluding poisonous gases. Thus the ratio was about 1 to 4.2.

Information is not available as to the total number of men killed in action in the French Army during the war. The total number of dead and missing was computed to be 1,357,800.[57] The total number of wounded from 1914 to 1918 was 2,052,984.[58] Although it is impossible from these figures to determine the ratio of killed in action to the total number wounded in the French Army, the general statement has been made that in the trench fighting on the western front, during the earlier years of the war, the ratio of killed to wounded was as 1 to 3; also, in the Battle of the Marne the ratio of killed to wounded was approximately 1 to 4.5.[59]

The total number of men in the British Army killed in action has been reported to be 464,049;[57] the number of missing (including prisoners) was 320,944.[57] The total number of wounded from August, 1914, to November, 1918, was 2,036,750.[57] Allowing 100,000 for the "presumed dead," the ratio of killed to wounded in the British armies was thus about 1 to 2.9.

In that part of the German Army opposite the French-Belgian-British front the total number killed in action was 789,400 and the number missing in action 968,197.[57] The number of wounded was 3,088,743.[57] Thus, assuming two-thirds of the missing were prisoners, the ratio of those reported killed to the total wounded was 1 to 2.8.

It would seem that the preponderance of trench warfare, especially on the western front in the World War, tended to increase the ratio of killed to wounded, while the preponderance of shell and other explosive missiles tended to decrease it. That these two factors did not offset each other—for in the war in France and Belgium as a whole the general ratio of killed to wounded was greater than that of previous recent wars, namely, about 1 to 3 or even more—is accounted for by the deadliness of the pointed rifle missile with which most of the contending armies were equipped. This deadliness had already been determined in the Turko-Balkan War of 1912–13, during which, though but 20 per cent of wounds were attributed to shrapnel, the ratio of killed to wounded was 1 to 2.5.[60]

The careful hunter of big game learns from a study of the effects of his bullets on the relatively few animals which fall to his fire more than he can possibly learn from years of experimental work on the rifle range. From a purely military standpoint it is greatly to be regretted that the military pathologist has hitherto been unable to make a similar adequate study of the site and type of the injury and the character of the missile in the bodies of men killed on the battle field. So far as the writer is aware, this phase of military pathologic research, which it may readily be seen would probably have a most important

bearing not only on military medical problems but also on the planning of body armor and the revising of weapons and missiles, was scarcely if at all touched on by any of the nations involved in the World War. In only relatively isolated instances did physicians, usually in first-aid service, have opportunities to make such examinations. These physicians were seldom trained pathologists, nor were they interested in the problems which might have been solved by careful study of the dead. Most of all, their duties to the living did not permit time to be given to such study.

Although, because of lack of observation and lack of records, most of our conclusions concerning the character of injury and the probable missile causing it in the battle dead have been drawn from inferences chiefly on conditions in the badly wounded, yet some of these inferences are worth recording.

While no accurate figures of the proportion of deaths on the battle field from primary hemorrhage are available, we are probably safe in estimating that from 80 to 85 per cent of such deaths were due to this cause. Relatively few wounded with central chest injuries or with injuries involving the abdominal aorta ever reached first-aid stations.

Immediate fatalities from head injuries, chiefly from snipers' fire, were very common in the early stages of trench warfare. These fatalities, however, were rapidly reduced to a minimum as men learned "to keep their heads down." Long-range sniping was largely at men whose entire bodies were exposed Here the sharpshooter aimed at the chest.

The total number of men reported as "missing," who were not captured and who were not deserters, but whose bodies had been blown into unidentifiable fragments, was relatively very much larger than in any previous wars. This was due to the great increase in number and size of high-explosive missiles.

Compared with previous wars, a relatively large number of instantaneous deaths occurred in action, particularly in trench warfare, without any sign of external injury to the body. In a few such bodies examined by pathologists many minute and occasionally large hemorrhages were found, usually in the central nervous system or lungs. Crile's experiments at Rouen, in 1917, on animals showed the lungs to be the seat of massive hemorrhages.[61] Crile found the central nervous system also involved. Durante and Mairet,[62] in similar experiments, found the central nervous system most affected. The exact physical condition producing these lesions has been much discussed. The most plausible hypothesis is that the very great instantaneous reduction of air pressure immediately following its very great increase from the gases of explosion causes such rapid displacement of gases and fluids inside the body as to rupture blood vessels with weak support, as in the lungs, and probably also to disintegrate cell membranes, particularly of the central nervous system.

RATIO OF WOUNDS FROM MISSILES FROM SMALL ARMS

In the open wars of the last 75 years prior to the Turko-Balkan war, approximately 90 per cent of the wounds were reported as having been caused from the fire of small arms, with approximately 10 per cent of the wounds

from bursting missiles from heavy gunfire.[63] The proportion of wounds from bayonets, sabers, and other piercing instruments has never been large and is rapidly decreasing, though the bayonet has been and still remains the cause of a considerable number of battle-field fatalities.

FIG. 74.—Sundry bayonets. A, United States; B, Great Britain; C, France; D, E, and F, Germany; G, United States Springfield, 1886 model

In the American Army during the World War the causative agent of wounds was either not designated or designated as "gunshot missile," with the kind not specified in approximately one-half of the battle wounds, by military destructive agents (76,076 of the 153,537 total admissions).[53] Of the remaining admissions the causative agent was stated as small-arms missile (rifle, machine gun, or

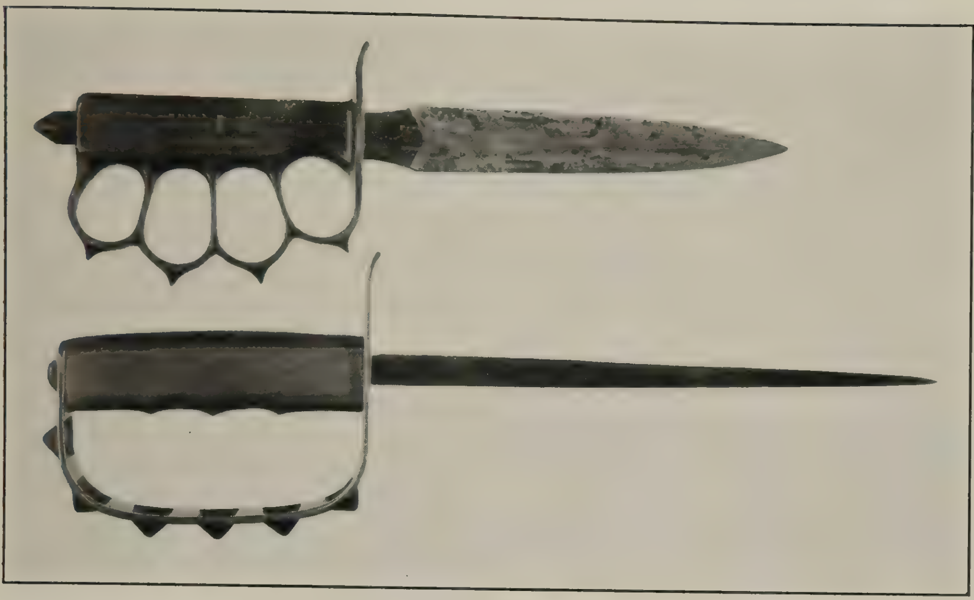

FIG. 75.—United States trench knives, models 1917 and 1918

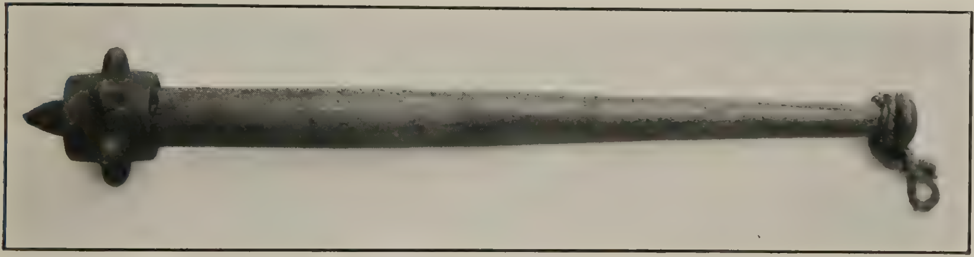

FIG. 76.—German coup stick or trench club

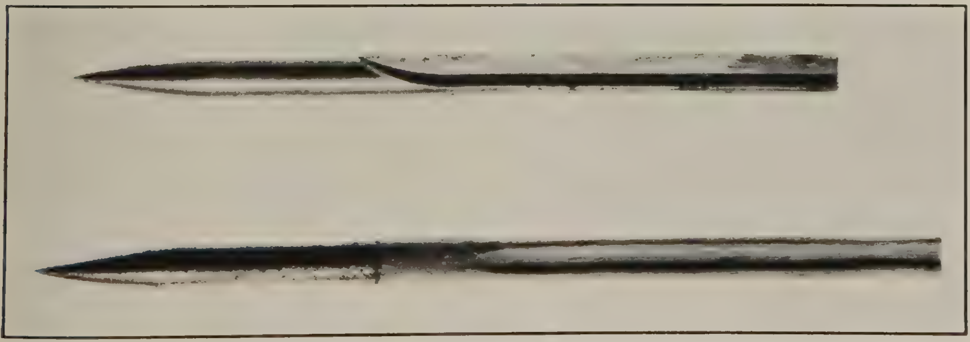

FIG. 77.—French steel darts which were dropped in showers from airplanes

pistol ball) in 20,662 admissions.[53] Missiles from shell, shrapnel, bombs, hand grenades, exploding mines, etc., were noted as the causative agent in 53,183 admissions.[53]

Thus, secondary missiles from exploding projectiles in the World War effected a much greater proportion of wound injury than in any previous war, while injury by direct missiles from the fire of small arms was proportionately greatly reduced. Taken as a whole, the percentage of wounds from exploding missiles probably varied, from 50 to 80 per cent being highest when battle conditions were most stabilized, as in trench warfare, thus resembling those of a siege, and lowest when the action became one of movement.

The great increase in the proportion of wounds from fragments of exploding missiles was due to the fact that not only in the barrage accompanying major engagements was there an unprecedented number of large-caliber weapons, each firing an unprecedented amount of high-explosive ammunition, but also under the daily siegelike conditions of trench warfare, long-range artillery fire was supplemented as never before by trench mortars, hand grenades, and rifle grenades and by aircraft bombs, almost all of which were charged with high explosives. Although the missiles from these soon dropped to relatively low velocities as compared with the velocities of missiles of small arms, their wounding energies were most effective.

The American military surgeons' refusal to hazard a guess as to the character of the causative agent of approximately half of all wounds needs no word of apology. The character of the wounds in a large share of instances was such as not to permit of even a reasonable guess as to the causative agent. Indeed, it is probable, on theoretic grounds, that many of the wounds of which the causative agent was described as secondary from an explosive missile may have been due to deformed direct missiles from small arms.

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CHAPTER III

STATISTICS

The statistics presented in the following pages for the American Expeditionary Forces, unless otherwise stated, include only data for the United States Army (not including marines), exclusive of troops in North Russia and in Siberia.

Revised statistics for battle casualties were published in the Surgeon General's Annual Report for 1920, Tables 1–43, inclusive (pp. 27–104, inclusive). As stated in that report, 5,768 military patients, whose admission had been caused by injuries received in battle in our expeditionary forces (exclusive of Russia and Siberia), remained in Army hospitals in the United States at the close of the calendar year 1919. Data for battle casualties published in the Surgeon General's Annual Report of 1920 could not include final disposition and time lost subsequent to January 1, 1920. Here, the later date of publication has resulted in more complete data.

Circular No. 87, W. D., March 29, 1921, required that all patients from the war army, officers excepted, remaining in hospital on July 2, 1921, should be discharged from the military service, thus separating them finally from Army records or military status.

In consequence of these instructions it has been possible to include all military data for battle wounded, including those for the men whose military service terminated between January 1, 1920, and July 2, 1921, and these will be found included in the final statistical tables for battle casualties which appear here.

Some of the tables which appear in this chapter are reproduced from the 1920 Annual Report of the Surgeon General, but no subsequent reference will be made here to that report. If any differences in the tables contained in this volume and in those published in the Surgeon General's Annual Report of 1920 are detected,[a] preference should be given to those published here, as every opportunity possible has been taken to perfect the tables and to eliminate any errors which might unavoidably have been included in the earlier tables.

No attempt is made to include killed in action. Reports were made to the Surgeon General's Office of only a small percentage of killed in action, and the information so furnished was too meager in character to be of any present value.

BATTLE INJURIES

ADMISSIONS

Lacerated wounds caused the admission of 46,549; penetrating wounds 42,374, and fractures 25,272.

[a] Excepting tables 23 and 24, casualties from gases have been excluded from the tables herein. It was not possible to do so in tables 23 and 24. Data on wounds from gases are given in Chaper VIII, Volume XIV of this history.—*Ed.*

TABLE 8.—*Battle injuries, admissions, officers and enlisted men, United States Army, 1917–18* [a]

ABSOLUTE NUMBERS

Diagnosis	Officers	Enlisted men				Total officers and men
		White	Colored	Color not stated	Total	
Dislocation	4	50	1	8	59	63
Contusion	31	555	17	97	669	700
Concussion	49	600	9	164	773	822
Crushing	9	18	3	19	40	49
Decapitation		1		1	2	2
Exhaustion and exposure	15	146	1	33	180	195
Foreign body, traumatic	1	32		6	38	39
Fractures	998	19,909	352	4,013	24,274	25,272
Gunshot wound, character of wound not specified	22	472	6	301	779	801
Sprain of joint	31	617	11	89	717	748
Strain	6	128	2	15	145	151
Traumatic amputation	12	552	8	118	678	690
Wound:						
Contused	32	910	25	159	1,094	1,126
Incised	1	66	2	13	81	82
Lacerated	1,516	36,070	677	8,286	45,033	46,549
Punctured	8	224	5	55	284	292
Extensive		6		4	10	10
Multiple	725	13,390	185	3,992	17,567	18,292
Penetrating	1,551	32,043	539	8,241	40,823	42,374
Perforating	499	10,684	187	1,901	12,772	13,271
Character and cause not stated	20	231	6	248	485	505
Others, traumatic	65	988	23	428	1,439	1,504
Total	5,595	117,692	2,059	28,191	147,942	153,537

[a] Source of information: Medical records sent to the Surgeon General's Office.

DEATHS

The total number of deaths from wounds received in action (not including deaths on field) was 12,470, a rate of 11.92 per 1,000 per annum; for enlisted men 11,881 deaths, rate 11.88; and officers 589, rate 12.57. (Table 9.) The deaths from penetrating wounds amounted to 4,976 or 4.75; multiple wounds 3,202, or 3.06; and fractures 2,751, or 2.63.

TABLE 9.—*Battle injuries, deaths from injuries, officers and enlisted men, United States Army, 1917–18* [a]

ABSOLUTE NUMBERS

Diagnosis	Officers	Enlisted men				Total officers and men
		White	Colored	Color not stated	Total	
Contusion		2		1	3	3
Concussion		4		7	11	11
Crushing	9	3	1	12	16	25
Decapitation		1		1	2	2
Exhaustion and exposure		1		1	2	2
Foreign body, traumatic		1			1	1
Fractures	117	1,686	24	924	2,634	2,751
Gunshot wound, character of wound not specified	3	55		70	125	128
Traumatic amputation	2	45		37	82	84
Wound:						
Contused	1	4			4	5
Lacerated	12	249	5	144	398	410
Punctured		1		2	3	3
Extensive		2		4	6	6
Multiple	142	1,650	16	1,394	3,060	3,202
Penetrating	245	2,566	30	2,135	4,731	4,976
Perforating	46	392	3	182	577	623
Character and cause not stated	3	11		72	83	86
Others, traumatic	9	52	1	90	143	152
Total	589	6.725	80	5,076	11,881	12,470

[a] Source of information: Medical records sent to the Surgeon General's Office.

DISCHARGES FOR DISABILITY

The number of discharges for disability among the enlisted men as the result of battle injuries amounted to 21,822; among officers, 508; with a total of 22,330 for the two. (Table 10.) Penetrating wounds caused the discharge for disability of 4,982; multiple wounds, 3,130; and fractures, 11,740, 46.6 per cent of the total discharges.

TABLE 10.—*Battle injuries, discharge for disability, officers and enlisted men, United States Army, 1917–18* [a]

ABSOLUTE NUMBERS

Diagnosis	Officers	Enlisted men				Total officers and men
		White	Colored	Color not stated	Total	
Dislocation		10			10	10
Contusion	1	5			5	6
Concussion		19		1	20	20
Crushing	1	8			8	9
Fractures	261	10,935	116	428	11,479	11,740
Gounshot wounds, kind not stated		1		1	2	2
Strain		3			3	3
Traumatic amputation	1	113	2	3	118	119
Wound:						
Contused		11			11	11
Incised		2			2	2
Lacerated	20	753	15	30	798	818
Punctured	1	5		1	6	7
Extensive		3		1	4	4
Multiple	65	2,898	43	124	3,065	3,130
Penetrating	116	4,522	51	293	4,866	4,982
Perforating	22	1,017	15	12	1,044	1,066
Character and cause not stated		9		6	15	15
Others, traumatic	20	342	9	15	366	386
Total	508	20,656	251	915	21,822	22,330

[a] Source of information: Medical records sent to the Surgeon General's Office.

DAYS LOST

The total number of days lost in hospital, including all time to July 1, 1921, amounted to 14,544,536 days. (Table 11.) The amount of time lost as the result of penetrating wounds was 3,697,759 days; multiple wounds, 2,017,208 days; fractures, 5,125,220 days, 29.3 per cent of the total. This does not really represent the total amount of time lost as the result of fractures, for as will be seen from Table 20, page 65, a number of fractures were tabulated as penetrating or perforating wounds.

TABLE 11.—*Battle injuries, days lost in hospital, officers and enlisted men, United States Army, 1917–18* [a]

ABSOLUTE NUMBERS

Diagnosis	Officers	Enlisted men				Total officers and enlisted men
		White	Colored	Color not stated	Total	
Contusion	962	23, 560	607	3, 972	28, 139	29, 101
Concussion	2, 569	24, 467	265	6, 410	21, 142	33, 711
Crushing	4	2, 370	197	607	3, 174	3, 178
Dislocation	203	4, 985	8	475	5, 468	5, 671
Exhaustion and exposure	284	4, 376	29	1, 577	5, 982	6, 266
Foreign body, traumatic	2	2, 109	7	59	2, 175	2, 177
Fractures	216, 347	4, 542, 472	56, 250	310, 151	4, 908, 873	5, 125, 220
Strain	342	5, 825	140	557	6, 522	6, 864
Traumatic amputation	810	54, 301	851	6, 000	61, 152	61, 962
Wound:						
Contused	1, 302	33, 753	637	4, 088	38, 478	39, 780
Incised	219	3, 169	218	420	3, 807	4, 026
Lacerated	68, 018	1, 854, 006	33, 541	253, 246	2, 140, 793	2, 208, 811
Punctured	563	12, 548	214	1, 683	14, 445	15, 008
Extensive		528		3	531	531
Multiple	74, 421	1, 750, 856	23, 520	168, 411	1, 942, 787	2, 017, 208
Penetrating	129, 732	3, 216, 466	45, 361	306, 200	3, 568, 027	3, 697, 759
Perforating	40, 661	962, 405	13, 067	111, 849	1, 087, 321	1, 127, 982
Character and cause not stated	624	18, 615	546	3, 713	22, 874	23, 498
Others, traumatic	4, 510	113, 610	1, 889	15, 774	131, 273	135, 783
Total	541, 573	12, 630, 421	177, 347	1, 195, 195	14, 002, 963	14, 544, 536

[a] Source of information: Medical records sent to the Surgeon General's Office.

DURATION OF TREATMENT

Of the 141,067 wounded who were treated in hospital, whose wounds did not result in death, the duration of treatment for 36,922 was 29 days or less, the average time per such case being 14.82 days. One hundred and four thousand one hundred and forty-five cases were treated in hospital for over 29 days, the average time for each such case being 133.25 days. (Table 12.) The average time in hospital for all cases that did not result in death was 102.26.

Fractures required the longest treatment the average time being 225.50 days. Only 1,530 fractures in a total of 22,521, not resulting in death, were returned to duty in 29 days or less.

TABLE 12.—*Battle injuries, duration of treatment (fatal cases excepted), classification by cases under 29 and over 29 days, officers and enlisted men, 1917–18* [a]

ABSOLUTE NUMBERS AND AVERAGE DAYS PER CASE

Battle injuries	Under 29 days			Over 29 days			Total		
	Number of cases	Number of days lost	Average time	Number of cases	Number of days lost	Average time	Number of cases	Number of days lost	Average time
Dislocation	21	252	12. 00	42	5, 419	129. 02	63	5, 671	90. 02
Contusion	370	4, 938	13. 35	327	24, 083	73. 65	697	29, 021	41. 64
Concussion	435	6, 144	14. 12	376	27, 522	73. 20	811	33, 666	41. 51
Crushing	5	94	18. 80	19	2, 955	155. 52	24	3, 049	127. 04
Exhaustion and exposure	118	1, 227	10. 40	75	5, 035	67. 13	193	6, 262	32. 45
Foreign body, traumatic	21	202	9. 62	17	1, 955	115. 00	38	2, 157	56. 76
Fractures	1, 530	21, 946	14. 34	20, 991	5, 056, 573	240. 89	22, 521	5, 078, 519	225. 50
Strain	74	1, 193	16. 12	77	5, 671	73. 65	151	6, 864	45. 45
Traumatic amputation	54	803	14. 87	552	60, 783	110. 11	606	61, 586	101. 63
Wounds:									
Contused	668	9, 726	14. 56	453	30, 033	66. 30	1, 121	39, 759	35. 47
Incised	41	525	12. 80	41	3, 501	85. 39	82	4, 026	49. 10
Lacerated	19, 264	285, 854	14. 84	26, 875	1, 917, 122	71. 33	46, 139	2, 202, 976	47. 75
Punctured	146	2, 233	15. 30	143	12, 579	87. 97	289	14, 812	51. 25
Extensive	1	9	9. 00	3	518	172. 67	4	527	131. 75
Multiple	2, 379	34, 864	14. 65	12, 711	1, 957, 558	154. 00	15, 090	1, 992, 422	132. 04
Penetrating	8, 034	117, 776	14. 66	29, 364	3, 544, 379	120. 70	37, 398	3, 662, 155	97. 92
Perforating	2, 383	48, 803	17. 96	10, 265	1, 078, 286	105. 04	12, 648	1, 121, 089	88. 64
Character and cause not stated	190	1, 613	8. 49	229	21, 677	94. 66	419	23, 290	55. 58
Others, traumatic	1, 188	14, 990	12. 62	1, 585	121, 972	76. 95	2, 773	136, 962	49. 39
Total	36, 922	547, 192	14. 82	104, 145	13, 877, 621	133. 25	141, 067	14, 424, 813	102. 26

[a] Source of information: Medical records sent to the Surgeon General's Office.

DAY OF DEATH

For the 12,470 who died in hospital as the result of wounds, the day of death was not stated in 930 instances. (Table 13.) Of the 12,707 deaths, for which the day of death was stated, 4,742 died on the first day. The proportional number who died on each day in hospital as the result of battle injuries is shown in Table 14.

TABLE 13.—*Battle injuries by diagnosis, deaths in hospital, showing the day of treatment on which death occurred, officers and enlisted men, United States Army, 1917–18* [a]

ABSOLUTE NUMBERS

Diagnosis	Concussion	Crushing	Fractures	Gunshot wound, character not specified	Traumatic amputation	Wound, lacerated	Wound, multiple	Wound, penetrating	Wound, perforating	Wound, character and cause not stated	Others, traumatic	Total
Day not stated		11	131	13	19	29	253	374	33	4	63	930
First day	7	10	762	80	42	104	1,344	2,086	178	69	60	4,742
Second day			316	14	9	32	418	665	84	3	12	1,553
Third day			167	4	2	20	205	292	37	3	5	735
Fourth day			109	3	2	18	112	170	25	1	5	445
Fifth day		1	88	1	1	13	83	102	19		2	310
Sixth day	1	1	85			15	75	128	20	2	2	329
Seventh day			55	1		11	75	101	11	1	1	256
Eighth day	1		53	4		3	46	82	18	1	2	210
Ninth day			59		1	9	36	76	17		2	200
Tenth day			47			10	32	64	18		1	172
Eleventh day			48	1		6	34	57	7			153
Twelfth day	2		53	1		10	21	53	15			155
Thirteenth day			38	1	1	11	33	53	9			146
Fourteenth day			25	2		8	21	33	10	1	2	102
Fifteenth day			17	1	2	5	15	46	4			90
Sixteenth day			23	1		8	22	37	9		1	101
Seventeenth day			32			7	17	31	5			92
Eighteenth day			25		1	3	23	40	3		1	96
Nineteenth day			25			5	12	32	6			80
Twentieth day			25			2	12	25	3		1	68
Twenty-first day			25		1	4	16	12	5			63
Twenty-second day			16	1		5	16	23	2			63
Twenty-third day			14			6	15	19	3			57
Twenty-fourth day			20			2	9	15			1	47
Twenty-fifth day			19			3	5	19	3			49
Twenty-sixth day			15			2	17	16	4			54
Twenty-seventh day			17			4	14	19	2		1	57
Twenty-eighth day			7			1	9	13	3			33
Twenty-ninth day			11			1	4	6	3		1	26
Thirtieth day			4			3	5	20	1			33
Thirty-first to thirty-fifth day			46		1	7	39	49	14			156
Thirty-sixth to fortieth day			44			4	25	40	11			124
Forty-first to forty-fifth day			30			2	20	32	2			86
Forty-sixth to fiftieth day		1	32			3	15	27	5		1	84
Fifty-first to fifty-fifth day			21			3	12	15	8			59
Fifty-sixth to sixtieth day			17			3	14	12	3			49
Sixty-first to sixty-fifth day		1	21			3	8	9	4		1	47
Sixty-sixth to seventieth day			20			5	11	11	3		1	51
Seventy-first to seventy-fifth day			23			3	10	6	2			44
Seventy-sixth to eightieth day			23		1	2	3	5	1	1		36
Eighty-first to eighty-fifth day			15			2	3	8	1			29
Eighty-sixth to ninetieth day			10			2	2	4	1			19
Ninety-first to ninety-fifth day			13		1	2	6	7				29
Ninety-sixth to one hundredth day			10				2	4	4		1	21
One hundred and first day and over			101			9	33	38	7		1	189
Total	11	25	2,757	128	84	410	3,202	4,976	623	86	168	12,470

[a] Source of information: Medical records sent to the Surgeon General's Office.

INVALIDED HOME

Forty-five thousand three hundred ninety-nine wounded were returned to the United States for further treatment. (Table 14.) Of this number 12,897 had received penetrating wounds and 15,542, or 34.23 per cent, had received

fractures. Of the total number of fracture cases (25,272) 61.5 per cent were returned to the United States for further treatment.

It should be explained here that all cases returned to the United States were not unfit for further military duty with the American Expeditionary Forces, for after the armistice, November 11, 1918, many cases were sent to the United States which otherwise would have been retained for treatment in Europe and ultimately returned for duty there.

TABLE 14.—*Battle injuries by diagnosis, wounded returned to the United States for further treatment, officers and enlisted men, United States Army, 1917–18* [a]

ABSOLUTE NUMBERS

Diagnosis	Number of cases	Per cent of total cases	Diagnosis	Number of cases	Per cent of total cases
Dislocations	20	31.75	Wound:		
Contusions	82	4.71	Contused	71	6.31
Concussion	62	7.54	Incised	10	12.20
Crushing	10	20.41	Lacerated	5,164	11.09
Decapitation	----------	----------	Punctured	57	19.52
Exhaustion and exposure	17	8.72	Extensive	----------	----------
Foreign body, traumatic	11	28.21	Multiple	7,047	38.53
Fractures	15,542	61.50	Penetrating	12,897	30.44
Gunshot wound, missile not specified	137	17.10	Perforating	3,392	25.56
Strain	15	9.94	Character and cause not stated	138	27.33
Traumatic amputation	265	38.41	Others, traumatic	462	20.52
			Total	45,399	----------

[a] Source of information: Medical records sent to the Surgeon General's Office.

MILITARY DESTRUCTIVE AGENTS

The effectiveness of the military agents used by the enemy in inflicting wounds in battle is of great interest and importance to the medico-military student. Tables 15, 16, 17, and 18 show the number of cases, deaths, discharges for disability, and days lost, for officers and enlisted men, and for the total, which occurred as the result of the various military agents.

TABLE 15.—*Battle injuries by military destructive agents, admissions, officers and enlisted men, United States Army, 1917–18* [a]

ABSOLUTE NUMBERS

Causative agent	Officers	Enlisted men				Total officers and enlisted men
		White	Colored	Color not stated	Total	
Not stated	63	767	17	346	1,130	1,193
Aerial bombing	4	94	18	8	120	124
Airplane	35	30	----------	9	39	74
Explosion	50	674	15	140	829	879
Crushing	3	70	5	4	79	82
Cutting and piercing instruments (others)	3	119	4	13	136	139
Bayonet	3	180	2	50	232	235
Saber	----------	11	----------	1	12	12
Gunshot missile, kind not specified	2,758	56,540	956	14,629	72,125	74,883
Pistol ball	12	196	12	22	230	242
Rifle ball	816	16,352	289	2,963	19,604	20,420
Shell and shrapnel	1,683	39,490	631	9,422	49,543	51,226
Hand grenade	31	672	33	144	849	880
Falling objects	8	115	18	27	160	168
Indirect result of military agent	60	994	18	187	1,199	1,259
Others, traumatic	66	1,388	41	226	1,655	1,721
Total	75,595	117,692	2,059	28,191	147,942	153,537

[a] Source of information: Medical records sent to the Surgeon General's Office.

TABLE 16.—*Battle injuries by military destructive agents—deaths from injuries, officers and enlisted men, United States Army, 1917–18* [a]

ABSOLUTE NUMBERS

Causative agent	Officers	Enlisted men				Total officers and enlisted men
		White	Colored	Color not stated	Total	
Not stated	10	49		82	131	141
Aerial bombing	1	8		7	15	16
Airplane	9	2		1	3	12
Explosion	1	9	1	4	14	15
Crushing		2		1	3	3
Cutting and piercing instruments (others)		1			1	1
Bayonet		2		2	4	4
Saber		2		1	3	3
Gunshot missile, kind not specified	362	4,033	44	3,035	7,112	7,474
Pistol ball		7	3	3	13	13
Rifle ball	51	592	6	312	910	961
Hand grenade	2	36	2	16	54	56
Falling objects	1	3	1	9	13	14
Indirect result of military agent	1	6		2	8	9
Others	5	30	1	24	55	60
Shell and shrapnel	146	1,943	22	1,577	3,542	3,688
Total	589	6,725	80	5,076	11,881	12,470

[a] Source of information: Medical records sent to the Surgeon General's Office.

TABLE 17.—*Battle injuries by military destructive agents, discharges for disability, officers and enlisted men, 1917–18* [a]

ABSOLUTE NUMBERS

Causative agent	Officers	Enlisted men				Total officers and enlisted men
		White	Colored	Color not stated	Total	
Not stated	15	107	2	9	118	133
Aerial bombing	1	38		1	39	40
Airplane	3	7			7	10
Explosions	2	162	6	3	171	173
Crushing	9				9	9
Cutting and piercing instruments (others)		5			5	5
Bayonet		9			9	9
Saber		2			2	2
Gunshot wounds, kind not stated	215	6,732	82	251	7,065	7,280
Pistol ball		26			26	26
Rifle ball	99	3,972	41	152	4,165	4,264
Shell and shrapnel	165	9,206	111	471	9,788	9,953
Hand grenade	1	176	3	18	197	198
Falling objects		5			5	5
Indirect result of military agents	3	117	2	9	128	131
Others	4	83	4	1	89	92
Total	508	20,656	251	915	21,822	22,330

[a] Source of information: Medical records sent to the Surgeon General's Office.

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TABLE 18. -*Battle injuries by military destructive agents, days lost in hospital, officers and enlisted men, United States Army, 1917–18* [a]

ABSOLUTE NUMBERS

Causative agent	Officers	Enlisted men				Total officers and enlisted men
		White	Colored	Color not stated	Total	
Not stated	2, 663	47, 359	877	10, 959	59, 195	61, 828
Aerial bombing	1, 079	12, 930	529	1, 147	14, 606	15, 685
Airplane	3, 722	4, 170		385	4, 555	8, 277
Explosions	3, 708	33, 756	1, 073	6, 019	40, 848	44, 556
Crushing	36	5, 940	533	398	6, 871	6, 907
Cutting and piercing instruments (other)	285	5, 626	126	130	5, 882	6, 167
Bayonet	369	8, 137	182	1, 296	9, 615	9, 984
Saber		1, 451	122	4	1, 577	1, 577
Gunshot missile, kind not specified	197, 447	5, 365, 341	69, 848	524, 815	5, 960, 004	6, 157, 451
Pistol ball	1, 915	18, 873	1, 035	1, 330	21, 238	23, 153
Rifle ball	106, 639	2, 063, 902	29, 387	173, 764	2, 267, 053	2, 373, 692
Shell and shrapnel	207, 930	4, 815, 191	65, 576	448, 416	5, 329, 183	5, 537, 113
Hand grenade	4, 144	68, 021	2, 509	7, 270	77, 800	81, 944
Falling objects	133	5, 490	915	1, 017	7, 422	7, 555
Indirect result of military agent	7, 518	65, 795	983	7, 560	74, 338	81, 856
Others	4, 015	108, 439	3, 652	10, 685	122, 776	126, 791
Total	541, 573	12, 630, 421	177, 347	1, 195, 195	14, 002, 963	14, 544, 536

[a] Source of information: Medical records sent to the Surgeon General's Office.

GUNSHOT MISSILES

There were 147,651 men wounded by missiles. Of this number, the kind of missile was not specified in 74,883 cases. In the 72,768 cases for which the missile was specified, rifle balls caused 20,420 wounds, or 28.06 per cent; shell and shrapnel 51,226, or 70.41 per cent; hand grenades 880, or 1.21 per cent; and pistol balls 242, or 0.33 per cent. The cases and deaths from missiles, with the case fatality for each, was shown in the following table:

TABLE 19.—*Battle injuries by missiles, admissions, deaths, and case fatality, officers and enlisted men, United States Army, 1917–18*

ABSOLUTE NUMBERS AND PERCENTAGE RATES

[Admissions and deaths from Tables 8 and 9, p. 58]

	Cases	Deaths	Case fatality (per cent)
Gunshot missile, kind not specified	74, 883	7, 474	9. 98
Pistol	242	13	5. 37
Rifle	20, 420	961	4. 71
Shell and shrapnel	51, 226	3, 688	7. 20
Hand grenade	880	56	6. 36

ALL CAUSES

As shown above, a very large percentage of the wounds received by American officers and soldiers during the World War, which resulted in admission to hospital, were caused by artillery missiles. In addition to the wounds caused by the artillery missiles, there were no doubt many wounds by machine-gun missiles, though these would be shown in the various tables as rifle wounds. As a result, a large percentage of the men wounded received multiple wounds. Considering only two wounds to one individual, there were 42,023 more wounds than wounded men. Many of the multiple wounded were from artillery missiles and consequently of a more severe type; which factor, combined with their multiplicity, resulted in a much higher fatality rate—9.7 per cent, as compared with 5.3 for single wounds.

ANATOMICAL PART AND MILITARY DESTRUCTIVE AGENTS; CASE FATALITY RATES

Table 20 shows, by the more important anatomical organs and parts, the number of wounds, deaths, and case fatality rates from rifle ball (including machine-gun bullet), shell, and shrapnel, and from other military agents (including the gunshot missiles not specified). In this table multiple wounds are included as well as single wounds; consequently, a death may be shown with a wound of a certain location or part, which would ordinarily not have resulted fatally, the patient at the same time having actually received a wound of another part, which caused the death. Therefore, the case fatality by regions, as here shown, is by no means literally true.

For long bones it is fair to presume that when a wound is reported this necessarily implies a fracture. Such an inference, however, should not be made for wounds of the joints or for those of the extremities. With wounds of the joints, or of the extremities, wounds were sometimes described as penetrating or perforating wounds, rather than fractures, even though fractures actually existed. Consequently, in Table 20, the number of cases shown as fractures for the joints or extremities do not necessarily include all of the fractures which were actually sustained.

TABLE 20.—*Battle injuries, by anatomical part and by military agent, admissions, deaths, and case fatalities, single and multiple wounds, officers and enlisted men, 1917–18* [a]

ABSOLUTE NUMBERS AND PERCENTAGE RATES

Locations and tissues	Admissions				Deaths				Case fatality			
	Rifle ball	Shell and shrapnel	Others and not specified	Total	Rifle ball	Shell and shrapnel	Others and not specified	Total	Rifle ball	Shell and shrapnel	Others and not specified	Total
Abdomen and pelvis:												
Organs—												
Anus	2	6	7	15	------	1	2	3	-------	-------	28.57	20.00
Appendix	1	------	4	5	1	------	1	2	100.00	-------	25.00	40.00
Bladder	33	25	67	125	14	13	40	67	42.42	52.01	59.70	53.60
Cecum	2	8	21	31	1	4	15	20	50.00	50.00	71.43	64.52
Colon	25	67	130	222	18	48	105	171	72.00	71.65	80.77	77.03
Diaphragm	11	19	37	67	4	13	28	45	36.36	68.43	75.68	67.16
Duodenum	2	2	6	10	2	1	5	8	100.00	50.00	83.33	80.00
Gall bladder	3	2	6	11	1	1	5	7	33.33	50.00	83.33	63.64
Ilium	18	30	55	103	10	21	44	75	55.56	70.00	80.00	72.82
Intestine, small	49	71	152	272	31	54	120	205	63.27	76.05	78.95	75.37
Jejunum	9	8	16	33	7	6	13	26	77.78	75.00	81.25	78.79
Kidney	25	39	65	129	15	20	40	75	60.00	51.28	61.54	58.14
Liver	44	83	131	258	25	53	95	173	56.82	63.85	72.52	67.05
Mesentery	5	6	2	13	2	2	2	6	40.00	33.33	100.00	46.15
Omentum	7	12	19	38	1	7	14	22	14.29	58.33	73.68	57.89
Pancreas	------	2	2	4	------	2	2	4	-------	100.00	100.00	100.00
Peritoneum	27	45	90	162	16	28	65	109	59.26	62.22	72.22	67.28
Rectum	22	29	51	102	10	11	27	48	45.45	37.93	52.94	47.06
Sigmoid	2	6	9	17	1	4	7	12	50.00	66.67	77.78	70.59
Spleen	9	11	31	51	7	7	20	34	77.78	63.64	64.52	66.67
Stomach	6	34	104	144	3	22	74	99	50.00	64.71	71.15	68.75
Ureter	1	3	-------	4	------	2	------	2	-------	66.67	-------	50.00
Bones and muscles—												
Ilium	92	149	191	432	13	33	65	111	14.13	22.15	34.03	25.69
Ischium	15	35	34	84	4	5	8	17	26.67	14.29	23.53	20.24
Pubic bone	11	11	39	61	3	5	8	16	27.27	45.46	20.51	26.23
Rectus abdominus	5	11	15	31	1	3	2	6	20.00	27.27	13.33	19.35
Sacrum	15	37	48	100	4	18	17	39	26.67	48.65	35.42	39.00
Regions—												
Epigastric	13	11	33	57	1	2	4	7	7.69	18.18	12.12	12.28
Hypochondriac	14	31	22	67	1	6	3	10	7.14	19.36	13.64	14.93
Hypogastric	1	2	8	11	------	------	2	2	-------	-------	25.00	18.18
Iliac	79	117	144	340	7	6	12	25	8.86	5.13	8.33	7.35
Inguinal	90	168	253	511	11	26	45	82	12.22	15.48	17.79	16.05
Umbilical	6	13	17	36	------	2	6	8	-------	15.38	35.29	22.22

[a] Source of information: Medical records sent to the Surgeon General's Office.

TABLE 20.—*Battle injuries, by anatomical part and by military agent, admissions, deaths, and case fatalities, single and multiple wounds, officers and enlisted men, 1917–18*—Continued

ABSOLUTE NUMBERS AND PERCENTAGE RATES—Continued

Locations and tissues	Admissions				Deaths				Case fatality			
	Rifle ball	Shell and shrapnel	Others and not specified	Total	Rifle ball	Shell and shrapnel	Others and not specified	Total	Rifle ball	Shell and shrapnel	Others and not specified	Total
Back:												
Bones and muscles—												
Coccyx	7	4	5	16	2	1	1	4	28.57	25.00	20.00	25.00
Rectus spinae	3	------	1	4	------	------	1	1	------	------	100.00	25.00
Regions—												
Cervical	25	24	53	102	9	7	19	35	36.00	29.17	35.85	34.31
Dorsal	94	171	229	494	17	30	53	100	18.09	17.54	23.14	20.24
Interscapular	1	12	26	39	------	------	3	3	------	------	11.54	7.69
Lumbar	209	664	855	1,728	19	48	86	153	9.09	7.23	10.01	8.85
Lumbo-sacral	1	3	15	19	1	1	------	2	100.00	33.33	------	10.53
Sacral	24	66	61	151	1	2	7	10	4.17	3.03	11.48	6.62
Face:												
Bones—												
Malar	10	23	31	64	------	1	3	4	------	4.35	9.68	6.25
Maxilla—												
Inferior	188	387	548	1,123	8	34	62	104	4.26	8.79	11.31	9.26
Superior	62	107	154	323	3	4	16	23	4.84	3.74	10.39	7.12
Nasal bone	9	33	35	77	------	1	------	1	------	3.03	------	1.30
Vomer	3	6	11	20	------	------	1	1	------	------	9.09	5.00
Zygoma	5	9	15	29	------	------	1	1	------	------	6.67	3.45
Parts—												
Chin	35	178	216	429	------	5	7	12	------	2.81	3.24	2.80
Cheek	246	1,137	1,487	2,870	6	15	32	53	2.44	1.32	2.15	1.85
Eye	141	854	1,189	2,184	7	24	54	85	4.96	2.81	4.54	3.89
Facial nerve	7	11	15	33	------	------	------	------	------	------	------	------
Lip—												
Lower	7	52	67	126	------	1	1	2	------	1.92	1.49	1.59
Upper	15	126	154	295	------	------	3	3	------	------	1.95	1.02
Lips, both	------	11	20	31	------	------	1	1	------	------	5.00	3.23
Mouth	13	34	54	101	------	2	4	6	------	5.88	7.41	5.94
Nose	61	274	335	670	------	2	6	8	------	.73	1.79	1.19
Parotid	1	9	4	14	------	------	------	------	------	------	------	------
Tongue	9	11	25	45	2	------	6	8	22.22	------	40.00	17.78
Regions—												
Infraorbital	6	45	53	104	------	------	1	1	------	------	1.89	.96
Orbital	9	22	38	69	1	1	1	3	11.11	4.55	2.63	4.35
Genital organs:												
Parts and location—												
Penis	21	62	63	146	------	2	8	10	------	3.23	12.70	6.85
Perineum	9	23	17	49	2	1	3	6	22.22	4.35	17.65	12.24
Scrotum	65	101	170	336	2	10	17	29	3.08	9.90	10.00	8.63
Testicle	28	90	112	230	2	7	8	17	7.14	7.78	7.14	7.39
Urethra	10	8	19	37	2	1	4	7	20.00	12.50	21.05	18.92
Head:												
Bones—												
Frontal	33	151	191	375	9	28	66	103	27.27	18.54	34.55	27.47
Mastoid	7	31	29	67	1	2	4	7	14.29	6.45	13.79	10.45
Occipital	23	98	130	251	3	18	49	70	13.04	18.37	37.69	27.89
Parietal	43	159	206	408	10	37	76	123	23.26	23.27	36.89	30.15
Skull—												
Base	14	93	219	326	6	61	163	230	42.86	65.59	74.43	70.55
Vault	47	145	268	460	19	75	165	259	40.43	51.72	61.57	56.31
Temporal	24	86	134	244	4	22	51	77	16.67	25.58	38.06	31.56
Parts—												
Auricle	24	79	140	243	------	------	2	2	------	------	1.43	.82
Brain	24	136	1,065	1,225	14	95	266	375	58.33	69.85	24.98	30.61
Ear	31	197	310	538	1	------	4	5	3.23	------	1.29	.93
Scalp	133	888	1,158	2,179	3	13	31	47	2.26	1.46	2.68	2.16
Ventricle	------	1	1	2	------	1	1	2	------	100.00	100.00	100.00
Regions—												
Forehead	52	351	462	865	------	10	14	24	------	2.85	3.03	2.77
Frontal	30	137	174	341	------	5	8	13	------	3.65	4.60	3.81
Mastoid	27	144	157	328	------	5	8	13	------	3.47	5.10	3.96
Occipital	54	307	373	734	1	10	15	26	1.85	3.26	4.02	3.54
Parietal	66	247	311	624	4	10	20	34	6.06	4.05	6.43	5.45
Supraorbital	29	176	196	401	------	3	2	5	------	1.71	1.02	1.25
Temporal	76	353	413	842	8	11	22	41	10.53	3.12	5.33	4.87
Lower extremity:												
Bones—												
Acetabulum	2	7	6	15	------	3	3	6	------	42.86	50.00	40.00
Astragalus	56	74	123	253	1	6	1	8	1.79	8.11	.81	3.16
Calcaneum	75	123	164	362	------	3	7	10	------	2.44	4.27	2.76
Cuboid	10	15	27	52	------	------	1	1	------	------	3.70	1.92

TABLE 20.—*Battle injuries, by anatomical part and by military agent, admissions, deaths, and case fatalities, single and multiple wounds, officers and enlisted men, 1917–18*—Continued

ABSOLUTE NUMBERS AND PERCENTAGE RATES—Continued

Locations and tissues	Admissions				Deaths				Case fatality			
	Rifle ball	Shell and shrapnel	Others and not specified	Total	Rifle ball	Shell and shrapnel	Others and not specified	Total	Rifle ball	Shell and shrapnel	Others and not specified	Total
Lower extremity—Continued.												
Bones—Continued.												
Cuneiform—												
External	10	14	24	48	------	------	------	------	------	------	------	------
Internal	9	7	22	38	------	------	------	------	------	------	------	------
Middle	9	10	13	32	------	------	------	------	------	------	------	------
Femur	710	1, 143	1, 918	3, 771	111	277	564	952	15. 63	24. 24	29. 41	25. 25
Fibula	418	882	1, 397	2, 697	22	111	223	356	5. 26	12. 58	15. 96	13. 20
Greater trochanter	12	30	34	76	3	1	4	8	25. 00	3. 33	11. 76	10. 53
Malleous	50	93	184	327	2	4	9	15	4. 00	4. 30	4. 89	4. 59
Metatarsus	278	357	638	1, 273	1	8	14	23	. 36	2. 24	2. 19	1. 81
Patella	67	163	222	452	5	14	31	50	7. 46	8. 59	13. 96	11. 06
Scaphoid (tarsal)	15	13	21	49	------	------	------	------	------	------	------	------
Tarsus (not specified)	51	74	123	248	------	7	8	15	------	9. 46	6. 50	6. 05
Tibia	709	1, 425	2, 245	4, 379	39	188	388	615	5. 50	13. 19	17. 28	14. 04
Location—												
Ankle—												
Fractures	1	5	6	12	------	------	1	1	------	------	16. 67	8. 33
Others [a]	246	658	1, 395	2, 299	------	20	26	46	------	3. 04	1. 86	2. 00
Total	247	663	1, 401	2, 311	------	20	27	47	------	3. 02	1. 93	2. 03
Hip—												
Fractures	------	1	9	10	------	------	2	2	------	------	22. 22	20. 00
Others [a]	369	1, 083	1, 656	3, 108	27	90	183	300	7. 32	8. 31	11. 06	9. 65
Total	369	1, 084	1, 665	3, 118	27	90	185	302	7. 32	8. 30	11. 11	9. 69
Knee—												
Fractures	2	9	8	19	------	5	1	6	------	55. 56	12. 50	31. 58
Others [a]	501	1, 856	2, 720	5, 077	11	80	126	217	2. 20	4. 31	4. 63	4. 27
Total	503	1, 865	2, 728	5, 096	11	85	127	223	2. 19	4. 56	4. 66	4. 38
Leg—												
Fractures	10	20	32	62	------	5	8	13	------	25. 00	25. 00	20. 97
Others [a]	2, 162	6, 422	9, 442	18, 026	50	384	727	1, 161	2. 31	5. 98	7. 70	6. 44
Total	2, 172	6, 442	9, 474	18, 088	50	389	735	1, 174	2. 30	6. 04	7. 76	6. 49
Thigh—												
Fractures	8	31	40	79	------	8	11	19	------	25. 81	27. 50	24. 05
Others [a]	2, 748	8, 153	10, 140	21, 041	75	440	677	1, 192	2. 73	5. 40	6. 68	5. 67
Total	2, 756	8, 184	10, 180	21, 120	75	448	688	1, 211	2. 72	5. 47	6. 76	5. 73
Other locations—												
Foot	796	1, 801	3, 106	5, 703	6	56	116	178	. 75	3. 11	3. 73	3. 12
Great toe	159	186	313	658	1	4	2	7	. 63	2. 15	. 64	1. 06
Heel	134	263	448	845	------	1	8	9	------	------	1. 79	1. 07
Popliteal space	56	136	155	347	2	6	11	19	3. 57	4. 41	7. 10	5. 48
Toe, not specified	182	236	475	893	1	2	7	10	. 55	. 85	1. 47	1. 12
Blood vessels—												
Femoral artery	13	25	40	78	3	8	15	26	23. 08	32. 00	37. 50	33. 33
Popliteal artery	9	12	6	27	------	1	------	1	------	8. 33	------	3. 70
Saphenous vein—												
External	2	2	8	12	------	2	3	5	------	100. 00	37. 50	41. 67
Internal	------	2	2	4	------	------	1	1	------	------	50. 00	25. 00
Tibial artery—												
Anterior	12	15	18	45	------	2	8	10	------	13. 33	44. 44	22. 22
Posterior	4	15	7	26	------	4	------	4	------	26. 67	------	15. 38
Nerves:												
Popliteal	2	2	4	8	------	------	1	1	------	------	25. 00	12. 50
Sciatic nerve, great	63	86	144	293	1	3	9	13	1. 59	3. 49	6. 25	4. 44
Tibial nerve, anterior	4	9	14	27	------	------	2	2	------	------	14. 29	7. 41
Tibial nerve, posterior	5	9	12	26	------	1	1	2	------	11. 11	8. 33	7. 69
Muscles and tendon:												
Adductor muscles	------	8	5	13	------	1	1	2	------	12. 50	20. 00	15. 38
Biceps femoris	2	5	3	10	------	1	------	1	------	20. 00	------	10. 00
Gastrocnemius	9	13	10	32	------	1	1	2	------	7. 69	10. 00	6. 25
Gluteal	589	2, 034	2, 477	5, 100	30	131	250	411	5. 09	6. 44	10. 09	8. 06
Quadriceps extensor femoris	2	[illegible]	11	19	------	------	1	1	------	------	9. 09	5. 26
Tendo Achillis	11	20	30	61	------	1	------	1	------	5. 00	------	1. 64

[a] "Others" properly include some fracture cases.

TABLE 20.—*Battle injuries, by anatomical part and by military agent, admissions, deaths, and case fatalities, single and multiple wounds, officers and enlisted men, 1917–18*—Continued

ABSOLUTE NUMBERS AND PERCENTAGE RATES—Continued

Locations and tissues	Admissions				Deaths				Case fatality			
	Rifle ball	Shell and shrapnel	Others and not specified	Total	Rifle ball	Shell and shrapnel	Others and not specified	Total	Rifle ball	Shell and shrapnel	Others and not specified	Total
Neck:												
Organs—												
Bronchus	2	9	331	342	------	------	4	4	-------	-------	1.21	1.17
Larynx	11	17	32	60	3	2	5	10	27.27	11.76	15.63	16.67
Pharynx	2	8	12	22	1	------	6	7	50.00	-------	50.00	31.82
Trachea	8	9	25	42	2	4	8	14	25.00	44.44	32.00	33.33
Blood vessels—												
Carotid artery	4	9	12	25	1	3	7	11	25.00	33.33	58.33	44.00
Jugular vein	3	10	14	27	2	7	4	13	66.67	70.00	28.57	48.15
Muscles and bones—												
Hyoid bone	-------	3	12	15	------	1	1	2	-------	33.33	8.33	13.33
Sternocleidomastoid	5	11	9	25	------	1	1	2	-------	9.09	11.11	8.00
Locations—												
Submaxillary	1	7	3	11	------	------	1	1	-------	-------	33.33	9.09
Submental	1	10	14	25	------	1	------	1	-------	10.00	-------	4.00
Spine:												
Parts and location—												
Spinal cord	47	36	137	220	41	36	99	176	87.23	100.00	72.26	80.00
Vertebra	70	114	194	378	25	42	91	158	33.33	36.84	46.91	41.80
Thorax:												
Organs or parts—												
Esophagus	-------	1	3	4	------	------	3	3	-------	-------	100.00	75.00
Heart and aorta	2	8	23	33	------	4	9	13	-------	50.00	39.13	39.39
Lungs	227	324	564	1,115	87	170	345	602	38.33	52.47	61.17	53.99
Pericardium	3	2	10	15	1	1	7	9	33.33	50.00	70.00	60.00
Pleura	125	171	263	559	26	61	109	196	20.80	35.67	41.44	35.06
Muscles and bones—												
Costal cartilage	3	6	6	15	------	1	------	1	-------	16.67	-------	6.67
Pectoral muscles	18	32	49	99	------	3	3	6	-------	9.37	6.12	6.06
Rib	113	227	389	729	27	52	110	189	23.89	22.91	28.28	25.93
Sternum	2	13	8	23	------	1	1	2	-------	7.69	12.50	8.70
Region—												
Infraclavicular	12	18	32	62	------	2	3	5	-------	11.11	9.38	8.06
Inframammary	9	10	14	33	1	------	2	3	11.11	-------	14.29	9.09
Infrascapular	15	49	40	104	------	1	------	1	-------	2.04	-------	.96
Mammary	46	73	110	229	3	3	14	20	6.52	4.11	12.73	8.73
Mediastinum	4	3	2	9	------	------	1	1	-------	-------	50.00	11.11
Scapular	-------	-------	-------	-------	------	------	------	------	-------	-------	-------	-------
Sternal	14	27	35	76	------	------	2	2	-------	-------	5.71	2.63
Subclavicular	10	13	14	37	------	3	2	5	-------	23.08	14.29	13.51
Supraclavicular	18	16	13	47	1	------	2	3	5.56	-------	15.38	6.38
Suprascapular	223	550	633	1,406	3	17	24	44	1.35	3.09	3.79	3.13
Upper extremities:												
Bones—												
Clavicle	84	171	242	497	6	8	18	32	7.14	4.68	7.44	6.44
Carpus (not specified)	28	59	114	201	------	3	4	7	-------	5.08	3.51	3.48
Cuneiform (carpal)	4	6	13	23	------	------	------	------	-------	-------	-------	-------
Humerus	724	1,289	2,007	4,020	29	137	233	399	4.01	10.63	11.61	9.93
Metacarpus	393	509	949	1,851	3	18	21	42	.76	3.54	2.21	2.27
Olecranon	47	85	108	240	3	5	7	15	6.38	5.88	6.48	6.25
Piseiform	-------	3	6	9	------	------	------	------	-------	-------	-------	-------
Radius	475	770	1,230	2,475	8	42	68	118	1.68	5.46	5.53	4.77
Scaphoid	11	16	27	54	------	1	------	1	-------	6.25	-------	1.85
Scapula	137	306	363	806	2	24	36	62	1.46	7.84	9.92	7.69
Trapezium	4	6	7	17	------	------	------	------	-------	-------	-------	-------
Trapezoid	2	4	7	13	------	------	1	1	-------	-------	14.29	7.69
Ulna	437	699	1,014	2,150	9	28	39	76	2.06	4.01	3.85	3.53
Unciform	5	4	10	19	------	1	------	1	-------	25.00	-------	5.26
Location—												
Arm—												
Fractures	3	22	24	49	------	7	8	15	-------	31.82	33.33	30.61
Others [a]	1,482	4,734	6,668	12,884	40	224	402	666	2.70	4.73	6.03	5.17
Total	1,485	4,756	6,692	12,933	40	231	410	681	2.69	4.86	6.13	5.27
Elbow—												
Fractures	1	4	8	13	------	1	------	1	-------	25.00	-------	7.69
Others [a]	168	557	784	1,509	------	11	27	38	-------	1.99	3.44	2.52
Total	169	561	792	1,522	------	12	27	39	-------	2.14	3.41	2.56

[a] "Others" properly include some fracture cases.

TABLE 20.—*Battle injuries, by anatomical part and by military agent, admissions, deaths, and case fatalities, single and multiple wounds, officers and enlisted men, 1917–18*—Continued

ABSOLUTE NUMBERS AND PERCENTAGE RATES—Continued

Locations and tissues	Admissions				Deaths				Case fatality			
	Rifle ball	Shell and shrapnel	Others and not specified	Total	Rifle ball	Shell and shrapnel	Others and not specified	Total	Rifle ball	Shell and shrapnel	Others and not specified	Total
Upper extremities—Continued.												
Location—Continued.												
Forearm—												
Fractures	6	7	12	25	------	2	1	3	------	28.57	8.33	12.00
Others [a]	764	2,085	2,781	5,630	5	46	87	138	.65	2.21	3.13	2.45
Total	770	2,092	2,793	5,655	5	48	88	141	.65	2.29	3.15	2.49
Shoulder joint—												
Fractures	2	4	4	10	------	------	1	1	------	------	25.00	10.00
Others [a]	1,169	3,317	4,801	9,287	32	148	291	471	2.74	4.46	6.06	5.07
Total	1,171	3,321	4,805	9,297	32	148	292	472	2.73	4.46	6.08	5.08
Wrist—												
Fractures	2	4	9	15	------	------	1	1	------	------	11.11	6.67
Others [a]	205	631	999	1,835	------	11	16	27	------	1.74	1.60	1.47
Total	207	635	1,008	1,850	------	11	17	28	------	1.73	1.69	1.51
Other locations—												
Finger, not specified	97	238	323	658	1	3	4	8	1.03	1.26	1.24	1.22
Finger, index	402	610	1,207	2,219	------	7	9	16	------	1.15	.75	.72
Finger, little	182	327	579	1,088	3	4	2	9	1.65	1.22	.35	.83
Finger, middle	287	398	840	1,525	2	1	8	11	.70	.25	.95	.72
Finger, ring	224	298	551	1,073	3	------	1	4	1.34	------	.18	.37
Hand	868	2,862	4,717	8,447	4	65	96	165	.46	2.27	2.04	1.95
Radiocarpal	1	------	1	2	------	------	------	------	------	------	------	------
Thumb	138	325	571	1,034	2	1	8	11	1.45	.31	1.40	1.06
Blood vessels—												
Axillary artery	1	1	3	5	------	1	1	2	------	100.00	33.33	40.00
Brachial artery	21	26	39	86	------	1	5	6	------	3.85	12.82	6.98
Cephalic vein	------	2	7	9	------	------	------	------	------	------	------	------
Median cephalic vein	------	1	2	3	------	1	------	1	------	100.00	------	33.33
Median vein	1	1	5	7	------	------	------	------	------	------	------	------
Radial artery	10	5	25	40	------	------	------	------	------	------	------	------
Ulnar artery	4	13	10	27	------	1	------	1	------	7.69	------	3.70
Nerves—												
Brachial plexus	21	32	49	102	------	1	1	2	------	3.13	2.04	1.96
Circumflex nerve	5	6	9	20	------	------	------	------	------	------	------	------
Median nerve	48	71	119	238	------	1	2	3	------	1.41	1.68	1.26
Musculospiral nerve	76	130	249	455	------	3	1	4	------	2.31	.40	.88
Radial nerve	14	28	38	80	------	------	------	------	------	------	------	------
Ulnar nerve	80	129	212	421	------	2	5	7	------	1.55	2.36	1.66
Muscles and regions—												
Acronial region	16	19	43	78	------	1	1	2	------	5.26	2.33	2.56
Axilla	108	244	302	654	2	12	28	42	1.85	4.92	9.27	6.42
Biceps cubiti	13	18	18	49	------	------	------	------	------	------	------	------
Deltoid muscle	48	76	104	228	------	1	1	2	------	1.32	.96	.88
Suprascapular	6	24	24	54	------	1	------	1	------	4.17	------	1.85
Suprasternum	1	------	3	4	------	------	------	------	------	------	------	------
Definite region not given:												
Arteries	45	69	152	266	9	26	64	99	20.00	37.68	42.11	37.22
Joints	7	4	23	34	------	1	2	3	------	25.00	8.70	8.82
Nerves	66	121	189	376	1	4	4	9	1.52	3.31	2.12	2.39
Phalanx	295	226	648	1,169	5	------	4	9	1.69	------	.62	.77
Soft tissues	75	47	107	229	1	1	1	3	1.33	2.13	.93	1.31
Tendons	20	50	80	150	------	1	------	1	------	2.00	------	.67
Veins	7	24	27	58	1	7	14	22	14.29	29.17	51.85	37.93
Total	23,625	60,485	90,186	174,296	1,167	4,191	8,111	13,469	4.94	6.93	8.99	7.73

[a] "Others" properly include some fracture cases.

BATTLE FRACTURES

Since fractures of the long bones of the extremities caused such a large percentage of the total deaths from wounds (2,019 out of 12,192, or 16.56 per cent) and such a large number of days was consumed in convalescence (3,582,248 days out of 14,444,536, or 24.8 per cent) it is desirable to make a special study of them. Tables 21 and 22 are devoted to the study in question.

In Table 21 a comparison is made by case fatality and loss of time, both for fatal cases and for those that did not result fatally; for the battle fractures, and for the simple and compound fractures, which occurred in the military service, but not as a result of injuries received in battle.

In Table 22 battle fractures involving the long bones of the extremities are summarized. In this table only the six long bones of the extremities are considered, and when any fracture of one of these bones was associated with a fracture of any other bone of the body or with a wound of any other tissue of the body, the secondary lesions are omitted from consideration. This table shows the number of cases involving only one of the six long bones, those involving two of them and lastly the total number of involvements of any of them. In this last section the excess number of cases, days, etc., is due to fractures involving two of these bones. For each of these classes, detailed information is given.

The greatest number of patients was for the humerus, 3,549; and the greatest number of fractures was also for the humerus, 4,069. The largest number of deaths among patients was for the femur, 804; and the greatest number of deaths for fractures was also for the femur, 971.

The highest case fatality was for fractures involving the fibula and radius. Since, however, this rate was based on only three cases, it is not significant. The highest case fatality rate (based on a significant number of cases) was for the fractures involving the femur and the humerus, 35.05 per cent.

TABLE 21.—*Fractures (all), battle and nonbattle, of long bones, officers and enlisted men, 1917–1919. Case fatality and average days lost. Percentage rates* [a]

Fractures	Fatality			Days lost per case								
				Total			Died			Recovered		
	Fractures, not in battle		Gunshot battle fractures	Fractures, not in battle		Gunshot battle fractures	Fractures, not in battle		Gunshot battle fractures	Fractures, not in battle		Gunshot battle fractures
	Simple	Compound		Simple	Compound		Simple	Compound		Simple	Compound	
Femur	3.49	19.50	25.22	178.2	230.6	249.1	6.9	11.0	18.6	184.4	283.8	326.9
Fibula	.24	5.04	13.20	73.7	157.3	222.3	37.0	56.1	9.5	73.7	162.6	254.6
Humerus	.20	5.05	10.17	85.5	173.7	218.6	39.0	42.0	14.6	85.6	180.7	241.7
Radius	.16	3.38	4.77	47.9	150.9	198.2	47.4	5.3	16.2	47.9	155.9	207.3
Tibia	.30	4.24	14.04	99.6	196.5	229.9	32.4	26.3	11.5	99.9	204.0	265.6
Ulna	.10	.89	3.53	45.3	130.4	192.2	19.0	6.0	6.0	45.3	131.5	205.3

[a] Source of information: Medical records sent to the Surgeon General's Office.

TABLE 22.—*Battle fractures of the long bones, admissions, deaths, recoveries, and case fatality, annual admissions, deaths and noneffective. Rates per 1,000*

Fractures	Cases				Days lost			Average days lost			Annual rates per 1,000		
	Total cases	Fatal cases	Recoveries	Fatality per cent	Total cases	Fatal cases	Recoveries	Total cases	Fatal cases	Recoveries	Total cases	Fatal cases	Total days
Fractures involving only one of the following long bones:													
Femur	3,296	804	2,492	24.39	859,547	16,053	843,494	260.8	20.0	338.5	3.15	0.77	2.25
Fibula	1,013	55	958	5.43	166,536	808	165,728	164.4	14.7	173.0	.97	.05	.44
Humerus	3,549	304	3,245	8.57	779,602	4,847	774,755	219.7	15.9	238.8	3.39	.29	2.04
Radius	1,492	48	1,444	3.22	257,131	1,477	255,654	172.3	30.8	177.0	1.43	.05	.67
Tibia	2,471	251	2,220	10.16	521,701	3,709	517,992	211.1	14.8	233.3	2.36	.24	1.37
Ulna	1,237	26	1,211	2.10	208,162	182	207,980	168.3	7.0	171.7	1.18	.02	.54
Fractures involving two of the following long bones:													
Femur and fibula	46	16	30	34.78	6,179	110	6,069	134.3	6.9	202.3	.04	.02	.02
Femur and humerus	194	68	126	35.05	31,449	810	30,639	162.1	11.9	243.2	.19	.06	.08
Femur and radius	73	17	56	23.29	13,078	150	12,928	179.2	8.8	230.9	.07	.02	.03
Femur and tibia	177	58	119	32.77	37,084	780	36,304	209.5	13.4	305.1	.17	.06	.10
Femur and ulna	64	8	56	12.50	11,866	138	11,728	185.4	17.3	209.4	.06	.01	.03
Fibula and humerus	27	5	22	18.52	4,524	34	4,490	167.6	6.8	204.1	.03	.00	.01
Fibula and radius	3	2	1	66.67	476	4	472	158.7	2.0	472.0	.00	.00	.00
Fibula and tibia	1,600	278	1,322	17.38	419,121	2,413	416,708	262.0	8.7	315.2	1.53	.27	1.10
Fibula and ulna	8	------	8	------	2,661	------	2,661	332.6	----	332.6	.01	----	.01
Humerus and radius	132	10	122	7.58	34,683	173	34,510	262.8	17.3	282.9	.13	.02	.09
Humerus and tibia	83	20	63	24.10	15,171	131	15,040	182.8	6.6	238.7	.08	.02	.04
Humerus and ulna	84	7	77	8.33	24,209	49	24,160	288.2	7.0	313.8	.08	.01	.06
Radius and tibia	33	7	26	21.21	9,796	13	9,783	296.8	1.9	376.3	.03	.01	.03
Radius and ulna	742	34	708	4.58	175,347	89	175,258	236.3	2.6	247.5	.71	.03	.46
Tibia and ulna	15	1	14	6.67	3,925	1	3,924	261.7	1.0	280.3	.01	.00	.01
Total and average	16,339	2,019	14,320	12.36	3,582,248	31,971	3,550,277	219.2	15.8	247.9	15.61	1.93	9.38
Fractures involving the following bones alone or in conjunction with one of the others named:													
Femur	3,850	971	2,879	25.22	959,203	18,041	941,162	249.1	18.6	326.9	3.68	.93	2.51
Fibula	2,697	356	2,341	13.20	599,497	3,369	596,128	222.3	9.5	254.6	2.58	.34	1.57
Humerus	4,069	414	3,655	10.17	889,638	6,044	883,594	218.6	14.6	241.7	3.89	.40	2.33
Radius	2,475	118	2,357	4.77	490,511	1,906	488,605	198.2	16.2	207.3	2.36	.11	1.28
Tibia	4,379	615	3,764	14.04	1,006,798	7,047	999,751	229.9	11.5	265.6	4.18	.59	2.64
Ulna	2,150	76	2,074	3.53	426,170	459	425,711	198.2	6.0	205.3	2.05	.07	1.12
Total and average	19,620	2,550	17,070	13.00	4,371,817	36,866	4,334,951	222.8	14.5	254.0	18.75	2.44	11.44
Excess of fractures over patients	3,281	531	2,750	------	789,569	4,895	784,674	------	----	------	------	----	------

PHYSICAL DISABILITIES FROM WOUNDS

Tables 23, 24, and 25 show the definite physical disabilities, which resulted from wounds received in battle, for cases in which the information furnished was definite and not too general in character to catalogue. Physical disabilities are catalogued for 19,768 men of the 25,187 who were discharged for disability. Thus in 5,419 the definite disabilities were not tabulated, but in many they were shown as associated diseases.

Amputations.—In Table 25 some of the more interesting final results of definite disabilities are considered. From this table it will be seen that the total number of soldiers who lost part of one or more extremities was 4,403. So far as the Surgeon General's Office has been able to determine, only one soldier who recovered lost both legs and one arm; 11 had amputations through both thighs, 1 through both legs at the knee; 9 had both legs amputated below the knee; 1 had both feet amputated; and 3 had one arm amputated above the elbow and one leg through the thigh.

Loss of eyes or eyesight.—If traumatic cataract is counted as the loss of the sight of an eye, 66 men lost either both eyes or the sight of both eyes. In 44 the loss of sight of both eyes was partial, and 644 men lost one eye or the sight of one eye.

Ankylosis.—Four thousand nine hundred and seventy soldiers had a partial or complete ankylosis of one or more joints.

TABLE 23.—*Summary of definite physical disabilities which resulted from battle injuries, officers and enlisted men, 1917–18*[a]

ABSOLUTE NUMBERS

Injuries	Number
Loss of extremities	
Upper extremity:	
One arm above elbow	550
One arm at elbow	41
Both forearms	3
One forearm	212
One hand at wrist	26
Both hands	1
One hand	18
Part of both hands	4
Part of one hand	1, 481
One arm and one forearm	1
One arm above elbow and part of hand	4
One arm below elbow and part of hand	1
One forearm and one hand	2
One hand and part of hand	2
Total	2, 346
Lower extremities:	
Both thighs	11
One thigh	1, 137
Both legs at knee	1
One leg at knee	95
Both legs below knee	9
One leg below knee	327
Both legs at ankle	3
One leg at ankle	131
Both feet	1
One foot	20
Part of both feet	3
Part of one foot	280
Thigh and leg at knee	2
Thigh and leg below knee	4
Leg at thigh and leg below knee	1
Leg at knee and part of foot	2
Leg below knee and foot	2
Leg below knee and part of foot	3
Total	2, 032
Upper and lower extremities:	
Arm above elbow and one thigh	3
Arm above elbow and leg below knee	1
Arm above elbow and one foot	1
Arm above elbow and part of one foot	1
Arm below elbow and one thigh	2
Arm below elbow and leg below knee	4
One hip and part of hand	1
Leg at thigh and part of hand	8
Leg at knee and part of hand	1
Leg below knee and part of hand	3
Total	25
Grand total	4, 403
Injuries to eyes	
Loss of both eyes	14
Loss of one eye	447
Loss of sight of both eyes	30
Loss of sight of one eye	170
Amaurosis	4
Amblyopia	37
Cataract, traumatic	27
Injuries to eyes—Continued	
Loss of eye and loss of sight of eye	13
Loss of eye and amblyopia	6
Loss of eye and cataract, traumatic	3
Loss of sight of one eye and amblyopia	1
Loss of sight of one eye and cataract, traumatic	2
Total	754
Ankylosis of joints	
Ankylosis:	
Bony, of—	
One hip	15
Both knees	4
One knee	104
Both ankles	1
One ankle	69
One shoulder	52
One elbow	101
One wrist	37
Spine	64
One knee and one ankle	1
Total	448
Fibrous, of—	
One hip	83
Both knees	1
One knee	407
Both ankles	5
One ankle	272
One shoulder	237
Both elbows	1
One elbow	352
Both wrists	1
One wrist	177
Foot, joints of	218
Hand, joints of	712
Hip and knee	2
Hip and hand	2
Knee and shoulder	3
Knee and wrist	1
Knee and hand	4
Knee and ankle	9
Ankle and shoulder	3
Ankle and foot	1
Ankle and hand	2
Foot and wrist	2
Shoulder and elbow	9
Shoulder and wrist	1
Shoulder and hand	1
Elbow and wrist	5
Elbow and hand	3
Wrist and hand	5
Total	2, 519
Partial, and deformities of—	
One hip	92
Both knees	13
One knee	478
Both ankles	5
One ankle	363
Both shoulders	1
One shoulder	330
Both elbows	2

[a] Source of information: Medical records sent to the Surgeon General's Office.

TABLE 23.—*Summary of definite physical disabilities which resulted from battle injuries, officers and enlisted men, 1917–18*—Continued

Injuries	Number	Injuries	Number
Ankylosis of joints—Continued		*Ankylosis of joints*—Continued	
Ankylosis—Continued.		Ankylosis—Continued.	
Partial, and deformities of—Continued.		Bony, and partial deformities of—	
One elbow	407	Knee and ankle	1
Both wrists	1	Ankle and shoulder	1
One wrist	207	Elbow and wrist	1
Hip and knee	2	Wrist and shoulder	1
Hip and ankle	3		
Knee and ankle	3	Total	4
Knee and shoulder	1		
Knee and elbow	1	Fibrous, and partial deformities of—	
Knee and wrist	1	Ankle and wrist	1
Ankle and elbow	1	Foot and ankle	2
Ankle and wrist	2	Foot and shoulder	1
Shoulder and elbow	4	Elbow and hip	1
Shoulder and wrist	1	Elbow and knee	1
Elbow and wrist	7	Wrist and shoulder	1
		Hand and knee	3
Total	1,925	Hand and ankle	2
		Hand and shoulder	5
Bony and fibrous—		Hand and elbow	6
Knee and ankle	1	Hand and wrist	20
Knee and foot	1		
Shoulder and knee	1	Total	43
Shoulder and hand	1		
Elbow and ankle	2	Sacroiliac	10
Wrist and shoulder	1	Temporomaxillary	12
Wrist and hand	1	Temporomaxillary and fibrous of wrist	1
Total	8	Grand total	4,970

TABLE 24.—*Associated physical disabilities (fatal cases excepted), resulting from battle injuries in 19,768 officers and enlisted men, 1917–18* [a]

Injuries	Number	Injuries	Number
Amaurosis	3	Ankylosis, bony, shoulder joint, left	16
and paralysis of facial nerve	1	and adherent scar	1
Amblyopia	28	Ankylosis, bony, spine	59
and adherent scar	1	and adherent scar	3
and disfigurement, facial	1	Ankylosis and fracture, faulty union	1
and loss of eye	1	and loss of leg at knee	1
Aneurism, abdominal	1	and neuritis, following injury	1
Aneurism, aorta thoracic	4	Ankylosis, bony, wrist, right	11
Aneurism, arm (location not given)		and ankylosis, partial and deformity, shoulder	1
and fracture, faulty union	1	and adherent scar	1
Aneurism, arteriovenous	5	Ankylosis, bony, wrist, left	17
Aneurism, artery, axillary	1	Ankylosis, fibrous, ankle, right	90
Aneurism, artery, carotid	1	and ankylosis, fibrous, shoulder	1
Aneurism, artery, femoral	3	and adherent scar	4
Aneurism, leg, right	1	Ankylosis, fibrous, ankle, left	126
Aneurism, thigh (location not given)	1	and ankylosis, fibrous, shoulder	1
Aneurism, unclassified	1	and arthritis, chronic, ankle	1
Ankylosis, bony, ankle, right	20	and adherent scar	5
and fracture, faulty union	1	and fracture, faulty union	1
and loss of leg at thigh	1	Ankylosis, fibrous, ankle, both	3
Ankylosis, bony, ankle, left	40	and adherent scar	1
and ankylosis partial and deformity, shoulder	1	and fracture, faulty union	1
Ankylosis and adherent scar	2	Ankylosis, fibrous, elbow, right	119
and fracture, faulty union	1	and amblyopia	1
Ankylosis, bony, ankle joints, both	1	and ankylosis, fibrous, shoulder	1
Ankylosis, bony, elbow joint, right	40	and ankylosis, fibrous, wrist	3
and ankylosis, fibrous, ankle	1	and adherent scar	5
and ankylosis, partial and deformity, wrist	1	and fracture, faulty union	3
and adherent scar	1	and paralysis of limb	1
Ankylosis, bony, elbow joint, left	38	Ankylosis, fibrous, elbow, left	120
and ankylosis, fibrous, ankle	1	and ankylosis, fibrous, elbow	1
Ankylosis, bony, hip joint, right	5	and ankylosis, fibrous, shoulder	1
Ankylosis, bony, hip joint, left	5	and ankylosis, fibrous, wrist	1
Ankylosis, bony, knee joint, right	40	and adherent scar	6
and ankylosis, bony, ankle	1	and fracture, faulty union	1
Ankylosis, bony, knee joint, left	49	Ankylosis, fibrous, foot, one or more joints (not ankle)	205
and amaurosis	1	and ankylosis, bony, knee	1
Ankylosis, bony, knee joints, both	4	and ankylosis, fibrous, ankle	1
Ankylosis, bony, shoulder joint, right	25	and ankylosis, fibrous, wrist	2
and ankylosis, fibrous, knee	1		

[a] Source of information: Medical records sent to the Surgeon General's Office.

TABLE 24.—*Associated physical disabilities (fatal cases excepted), resulting from battle injuries, in 19,768 officers and enlisted men, 1917–18*—Continued

Injuries	Number
Ankylosis and ankylosis, partial and deformity, ankle	2
and ankylosis, partial and deformity, shoulder	1
and arthritis, chronic, ankle	1
and adherent scar	6
and flail joint, ankle	1
and fracture, faulty union	3
and loss of sight, one eye	1
and tendon, severed and contracted	1
Ankylosis, fibrous, hand or finger, one or more joints	652
and ankylosis, bony, wrist	1
and ankylosis, bony, shoulder	1
and ankylosis, fibrous, ankle	2
and ankylosis, fibrous, elbow	3
and ankylosis, fibrous, hip	2
and ankylosis, fibrous, knee	4
and ankylosis, fibrous, shoulder	1
and ankylosis, fibrous, wrist	5
and ankylosis, partial and deformities, ankle	2
and ankylosis, partial and deformities, elbow	6
and ankylosis, partial and deformities, knee	3
and ankylosis, partial and deformities, shoulder	5
and ankylosis, partial and deformities, wrist	20
and adherent scar	35
and disfigurement, facial	2
and fracture, faulty union	11
and fracture, nonunion	1
and loss of leg at thigh	1
and loss of sight, one eye	3
and paralysis of facial nerve	1
and paralysis of limb	3
and tendon, severed and contracted	2
and loss of leg below knee	1
Ankylosis, fibrous, hip, right	29
and ankylosis, fibrous, knee	1
Ankylosis, fibrous, hip joint, left	31
and ankylosis, fibrous, knee	1
and adherent scar	2
and fracture, faulty union	1
Ankylosis, fibrous, knee, right	169
and ankylosis, fibrous, ankle	5
and ankylosis, fibrous, shoulder	1
and adherent scar	9
and fracture, faulty union	1
Ankylosis, fibrous, knee joint, left	135
and ankylosis, bony, knee	1
and ankylosis, fibrous, ankle	4
and adherent scar	7
and fracture, faulty union	2
Ankylosis, fibrous, knee joints, both	1
Ankylosis, fibrous, shoulder, left	89
and ankylosis, fibrous, elbow	4
and ankylosis, fibrous, knee	1
and ankylosis, fibrous, wrist	1
and adherent scar	5
and facial disfigurement	2
Ankylosis, fibrous, shoulder joint, right	88
and ankylosis, bony, wrist	1
and ankylosis, fibrous, ankle	1
and ankylosis, fibrous, elbow	3
and ankylosis, fibrous, knee	1
and adherent scar	3
and fracture, faulty union	2
Ankylosis, fibrous, shoulder, both	1
Ankylosis, fibrous, wrist, right	58
and ankylosis, fibrous, elbow	1
and adherent scar	3
Ankylosis, fibrous, wrist, left	68
and ankylosis, fibrous, knee	1
and adherent scar	3
and fracture, faulty union	2
Ankylosis, fibrous, wrist, both	1
Ankylosis, partial and deformities, ankle, right	137
and ankylosis, bony, knee	1
and ankylosis, partial and deformities, knee	1
and ankylosis, partial and deformities, wrist	1
and adherent scar	3
and tendon, adherent in scars	1
Ankylosis, partial and deformities, ankle, left	159
and ankylosis, partial and deformities, wrist	1
and arthritis, chronic, knee	1
and adherent scar	10
Ankylosis and fracture, faulty union	1
and hernia	1
Ankylosis, partial and deformities, ankle joints, both	5
Ankylosis, partial and deformities, elbow joint, right	164
and ankylosis, partial and deformities, knee	1
and ankylosis, partial and deformities, shoulder	1
and ankylosis, partial and deformities, wrist	5
and adherent scar	3
Ankylosis, partial and deformities, elbow joint, left	162
and ankylosis, partial and deformities, ankle	1
and ankylosis, partial and deformities, wrist	1
and arthritis, chronic, shoulder	1
and adherent scar	7
and frature, faulty union	1
and loss of leg at knee	1
and paralysis of facial nerve	1
and paralysis of limb, lower, from cord injuries	1
Ankylosis, partial and deformities, elbow joints, both	2
Ankylosis, partial and deformities, hip joint, right	33
Ankylosis, partial and deformities, hip joint, left	36
and ankylosis, fibrous, elbow	1
and adherent scar	1
Ankylosis, partial and deformities, knee joint, right	212
and ankylosis, fibrous, elbow	1
and ankylosis, partial and deformities, ankle	3
and ankylosis, partial and deformities, hip	1
and ankylosis, partial and deformities, wrist	1
and adherent scar	7
and fracture, faulty union	1
Ankylosis, partial and deformities, knee joint, left	206
and ankylosis, partial and deformities, ankle	2
and ankylosis, partial and deformities, hip	1
and adherent scar	1
and fracture, faulty union	1
Ankylosis, partial and deformities, knee joints, both	13
Ankylosis, partial and deformities, shoulder joint, right	133
and ankylosis, fibrous, wrist	1
and ankylosis, partial and deformities, elbow	1
and adherent scar	4
and tendon, adherent in scars	1
Ankylosis, partial and deformities, shoulder joint, left	138
and ankylosis, partial and deformities, elbow	2
and ankylosis, partial and deformities, knee	1
and adherent scar	5
Ankylosis, partial and deformities, shoulder joints, both	1
Ankylosis, partial and deformities, wrist joint, right	71
and ankylosis, fibrous, ankle	1
and ankylosis, partial and deformities, elbow	1
and ankylosis, partial and deformities, shoulder	1
and adherent scar	1
and fracture, faulty union	1
and tendon adherent in scars	1
Ankylosis, partial and deformities, wrist joint, left	97
and ankylosis, partial and deformities, wrist	1
and adherent scar	4
and aphasia	4
Ankylosis, sacroiliac joint	9
and loss of sight, one eye	1
Ankylosis, temporomaxillary joint	8
and amblyopia	1
and ankylosis, fibrous, wrist	1
and adherent scar	1
and facial disfigurement	1
and loss of eye	1
Arthritis, chronic, ankle, right	11
and ankylosis, partial and deformities, ankle	1
Arthritis, chronic, ankle, left	9
Arthritis, chronic, elbow, right	5
Arthritis, chronic, elbow, left	1
and ankylosis, partial and deformities, elbow	1
Arthritis, chronic, hip, right	3
Arthritis, chronic, hip, left	2

TABLE 24.—*Associated physical disabilities (fatal cases excepted), resulting from battle injuries, in 19,768 officers and enlisted men, 1917–18*—Continued

Injuries	Number
Arthritis, chronic, knee, right	20
and adherent scars	1
Arthritis, chronic, knee, left	14
and ankylosis, bony, wrist	1
Arthritis, chronic, knees, both	2
Arthritis, chronic, shoulder, right	3
Arthritis, chronic, shoulder, left	2
Arthritis, chronic, spine	3
Arthritis, chronic, wrist, right	3
Arthritis, chronic, wrist, left	4
Arthritis, chronic, wrists, both	1
Asthma	9
Atrophy of muscle, lower extremity	88
and ankylosis, bony, knee	1
and ankylosis, fibrous, ankle	2
and ankylosis, fibrous, knee	1
and ankylosis, partial and deformities, ankle	7
and ankylosis, partial and deformities, hip	2
and ankylosis, partial and deformities, knee	4
and adherent scar	10
and fracture, faulty union	2
and neuritis following injury	1
and paralysis of limb	2
Atrophy of muscle, upper extremity	103
and ankylosis, bony, elbow	1
and ankylosis, fibrous, elbow	4
and ankylosis, fibrous, shoulder	2
and ankylosis, partial and deformities, ankle	1
and ankylosis, partial and deformities, elbow	3
and ankylosis, partial and deformities, knee	1
and ankylosis, partial and deformities, shoulder	7
and ankylosis, partial and deformities, wrist	1
and adherent scar	5
and fracture, faulty union	1
and loss of hearing, one side	1
and loss of leg below knee	1
and paralysis of facial nerve	1
and paralysis of limb	4
and pleurisy, chronic	1
Bronchitis, chronic	2,281
and amblyopia	4
and ankylosis, fibrous, elbow	1
and ankylosis, fibrous, knee	1
and ankylosis, partial and deformities, elbow	1
and ankylosis, partial and deformities, knee	1
and ankylosis, partial and deformities, shoulder	1
and asthma	5
and adherent scar	5
and fracture, faulty union	1
and loss of hearing, one side	2
and loss of sight, one eye	1
and neuritis following injury	1
and paralysis of facial nerve	1
and tendon severed and contracted	1
Bulbar palsy	1
Cardiac arryhthmia, others	3
Cardiac dilitation	4
Cardiac disorders, functional	100
and adherent scar	1
and synovitis, chronic	1
Cardiac hypertrophy	4
Cardiac hypertrophy and dilitation	3
Cataract, traumatic	22
and adherent scar	2
and facial disfigurement	2
and loss of arm above elbow	1
and loss of arm below elbow	1
and loss of sight, one eye	2
Cataract and loss of eye	3
Chest, deformities of, from injury	7
Conjunctivitis, chronic	24
and amblyopia	1
Contracture, arm, right	3
Contracture, arm, left	4
and fracture, faulty union	1
Contracture, leg, right	6
and ankylosis, partial and deformities, knee	1
Contracture, leg, left	9
and ankylosis, fibrous, knee	1
and ankylosis, partial and deformities, ankle	1
and adherent scar	1
Contracture, legs, both	2
Convalescent from wounds	554
and ankylosis, partial and deformities, ankle	2
and ankylosis, partial and deformities, elbow	3
and ankylosis, partial and deformities, knee	1
and ankylosis, partial and deformities, shoulder	2
and ankylosis, partial and deformities, wrist	2
and adherent scar	6
and fracture, faulty union	3
and fracture, nonunion	1
and loss of sight, one eye	1
and tendon, severed and contracted	1
Deformities, larynx	
and ankylosis, partial and deformities, shoulder	1
Disfigurement, facial	43
and amblyopia	1
and ankylosis, partial and deformities, knee	1
and adherent scar	6
Disfigurement, head	3
Epilepsy	5
Epilepsy, Jacksonian	1
False joint of femur, right side	1
False joint of fibula, right side	1
False joint of fibula and tibia, right side	1
Fistula, biliary	1
Fistula, fecal	6
and ankylosis, fibrous, hip	1
Fistula, other	3
and amblyopia	1
and rectum, loss of control of sphincter	1
Fistula, rectovesical	1
Fistula, retroureteral	1
Flail joint, ankle joint, right	1
Flail joint, ankle joint, left	1
Flail joint, elbow joint, right	3
Flail joint, elbow joint, left	5
Flail joint, elbow joint, both	1
Flail joint, hip joint, left	1
Flail joint, knee joint, right	2
Flail joint, knee joint, left	2
Flail joint, shoulder joint, right	6
Flail joint, shoulder joint, left	2
and fracture, faulty union	1
Flail joint, wrist joints, both	1
Flat foot, traumatic, right	3
Flat foot, traumatic, left	2
and fracture, faulty union	1
Flat foot, traumatic, both	2
Fractures, deforming	548
and ankylosis, bony, ankle	1
and ankylosis, bony, hip	1
and ankylosis, fibrous, ankle	3
and ankylosis, fibrous, elbow	2
and ankylosis, fibrous, hip	2
and ankylosis, fibrous, knee	5
and ankylosis, fibrous, wrist	2
and ankylosis, partial and deformities, ankle	6
Fracture and ankylosis, partial and deformities, elbow	13
and ankylosis, partial and deformities, hip	3
and ankylosis, partial and deformities, knee	9
and ankylosis, partial and deformities, shoulder	3
and ankylosis, partial and deformities, wrist	4
and adherent scar	18
and facial disfigurement	2
and fracture, faulty union	1
and loss of hearing, one side	1
and nerves severed and contracted	1
and paralysis of limb	1
and synovitis, chronic	1
Fracture, faulty union	292
and amblyopia	1
and ankylosis, bony, knee	2
and ankylosis, fibrous, ankle	5
and ankylosis, fibrous, elbow	4
and ankylosis, fibrous, hip	1
and ankylosis, fibrous, knee	16
and ankylosis, fibrous, wrist	1
and ankylosis, partial and deformities, ankle	2
and ankylosis, partial and deformities, hip	1

TABLE 24.—*Associated physical disabilities (fatal cases excepted), resulting from battle injuries, in 19,768 officers and enlisted men, 1917–18*—Continued

Injuries	Number
Fracture and ankylosis, partial and deformities, knee	2
and ankylosis, partial and deformities, shoulder	1
and arthritis, chronic, ankle	1
and adherent scar	13
and facial disfigurement	2
and loss of hearing, one side	1
and paralysis of limb	1
Fractures, old, ununited	34
and ankylosis, fibrous, knee	1
and ankylosis, partial and deformities, elbow	1
and ankylosis, partial and deformities, hip	1
and ankylosis, partial and deformities, shoulder	1
and ankylosis, partial and deformities, wrist	3
and adherent scar	2
Glaucoma, secondary	1
Heel, painful	2
Hemiplegia	39
and adherent scar	1
and paralysis of facial nerve	1
and loss of eye	1
Hernia, cerebral	2
and amblyopia	1
Hernia of muscle	10
and ankylosis, fibrous, elbow	1
and ankylosis, partial and deformities, elbow	1
and adherent scar	2
and paralysis of limb	1
Hernia, ventral	15
and ankylosis, fibrous, shoulder	1
and adherent scar	2
and loss of sight, one eye	1
and loss of eye	1
Insanity, total	2
Intestines, adhesions of	26
Intestines, fistula of	1
Intestines, obstruction	2
Intestines, partial loss of	2
Kidney, loss of one, sequelæ	4
and ankylosis, fibrous, wrist	1
and adherent scar	1
Laryngitis, chronic	42
and amblyopia	1
and adherent scar	1
Leucoma	18
Leucoma and adherent scar	2
and loss of eye	1
Ligament, relaxation of	16
Loss of arm, right	102
and ankylosis, partial and deformities, shoulder	1
and adherent scar	1
Loss of arm, left	106
and ankylosis, partial and deformities, ankle	2
and ankylosis, partial and deformities, knee	1
and ankylosis, partial and deformities, shoulder	1
and loss of hearing, one side	1
Loss of arm above elbow, right	153
and loss of eye	1
Loss of arm above elbow, left	168
and ankylosis, fibrous, knee	1
and ankylosis, partial and deformities, shoulder	1
and paralysis of facial nerve	1
Loss of arm at elbow, right	20
Loss of arm at elbow, left	20
and ankylosis, knee	1
Loss of bone tissue	266
and amblyopia	2
and ankylosis, bony, elbow	3
and ankylosis, bony, hip	3
and ankylosis, bony, knee	4
and ankylosis, bony, shoulder	5
and ankylosis, bony, wrist	2
and ankylosis, fibrous, ankle	10
and ankylosis, fibrous, elbow	3
and ankylosis, fibrous, hip	4
and ankylosis, fibrous, knee	11
and ankylosis, fibrous, shoulder	13
and ankylosis, fibrous, wrist	4
and ankylosis, partial and deformities, ankle	8
and ankylosis, partial and deformities, elbow	10
and ankylosis, partial and deformities, hip	4
and ankylosis, partial and deformities, knee	6
Loss of bone tissue and ankylosis, partial and deformities, shoulder	5
and ankylosis, partial and deformities, wrist	4
and arthritis, chronic, knee	1
and arthritis, chronic, wrist	1
and adherent scars	41
and contracture limb, lower	1
and facial disfigurement	11
and head disfigurement	3
and epilepsy	1
and fistula, fecal	2
and fistula, urinary	1
and flail joint, elbow	2
and flail joint, shoulder	3
and fracture, union	19
and fracture, faulty, nonunion	6
and neuritis, following injury	1
and optic atrophy	2
and paralysis of facial nerve	3
and paralysis of limb	4
and pleurisy, chronic	1
and tendon adherent in scars	1
and tendon severed and contracted	2
and loss of eye	1
and loss of leg below knee	2
Loss of forearm above wrist, right	79
and ankylosis, bony, elbow	1
and epilepsy, Jacksonian	1
and loss of arm above elbow	1
and loss of hand	1
and loss of leg below knee	2
Loss of forearm above wrist, left	131
and ankylosis, fibrous, knee	1
and adherent scar	2
and loss of eye	1
Loss of forearm and loss of hand	1
and loss of leg below knee	1
Loss of forearms above wrist, both	3
Loss of ear, right	1
and loss of hearing, one side	1
Loss of ear, left	6
Loss of eye, right	200
and amblyopia	3
and ankylosis, bony, elbow	1
and ankylosis, fibrous, knee	1
and ankylosis, fibrous, shoulder	1
and adherent scar	4
and facial disfigurement	7
and loss of arm above elbow	1
and loss of sight, one eye	3
and optic atrophy	1
Loss of eye, left	199
and amblyopia	2
and ankylosis, fibrous, ankle	2
and ankylosis, fibrous, knee	2
and ankylosis, partial and deformities, knee	1
and adherent scar	2
and facial disfigurement	6
and loss of hearing, one side	1
and loss of sight, one eye	7
and paralysis of facial nerve	1
Loss of eyes, both	14
Loss of foot, right	12
and loss of arm, above elbow	1
Loss of foot, left	8
Loss of feet, both	1
Loss of foot, part of right	127
and ankylosis, fibrous, hip	2
and ankylosis, fibrous, knee	2
and ankylosis, fibrous, wrist	2
and ankylosis, partial and deformities, ankle	3
and ankylosis, partial and deformities, knee	1
and adherent scar	1
and loss of hearing, one side	1
and loss of leg below knee	1
and paralysis of facial nerve	1
and paralysis of limb	1
Loss of foot, part of, left	129
and ankylosis, fibrous, ankle	2
and ankylosis, fibrous, knee	1
and adherent scar	1
and fracture, faulty union	2
and loss of arm above elbow	1
and loss of eye	1

TABLE 24.—*Associated physical disabilities (fatal cases excepted), resulting from battle injuries, in 19,768 officers and enlisted men, 1917–18*—Continued

Injuries	Number
Loss of foot and loss of hearing, one side	1
and loss of leg, below knee	2
and loss of leg at knee	2
and optic atrophy	1
and paralysis of limb	1
Loss of feet, part of both	3
Loss of hand, all, right	6
Loss of hand, all, left	10
and adherent scar	1
and loss of sight, both eyes	1
Loss of hand, all, both	1
Loss of hand at wrist, right	10
and ankylosis, partial and deformities, elbow	1
Loss of hand at wrist, left	14
and adherent scar	1
Loss of hand, part of right	563
and ankylosis, bony, shoulder	1
and ankylosis, bony, wrist	1
and ankylosis, fibrous, knee	2
and ankylosis, fibrous, shoulder	3
and ankylosis, fibrous, wrist	2
and ankylosis, partial and deformities, ankle	1
and ankylosis, partial and deformities, elbow	1
and ankylosis, partial and deformities, knee	1
and ankylosis, partial and deformities, wrist	1
Loss of hand and adherent scar	7
and facial disfigurement	2
and fracture, faulty union	3
and loss of arm above elbow	3
and loss of arm below elbow	1
and loss of eye	1
and loss of hand, side not specified	2
and loss of leg below knee	2
and loss of leg at hip	1
and loss of leg at knee	1
and loss of leg at thigh	5
and loss of sight, one eye	3
and paralysis of limb	4
and paralysis of limb, upper, from cord injuries	1
and tendon, adherent, in scars	3
Loss of hand, part of, left	836
and ankylosis, bony, shoulder	1
and ankylosis, fibrous, elbow	1
and ankylosis, fibrous, hip	1
and ankylosis, fibrous, knee	2
and ankylosis, fibrous, wrist	2
and ankylosis, partial and deformities, elbow	3
and ankylosis, partial and deformities, hip	1
and ankylosis, partial and deformities, wrist	3
and adherent scar	12
and fistula, urinary	1
and fracture, faulty union	5
and fracture, nonunion	1
and loss of arm above elbow	1
and loss of ear	1
and loss of eye	3
and loss of hearing, one side	1
and loss of leg below knee	1
and loss of leg at thigh	3
and paralysis of limb	3
and pleurisy, chronic	1
and tendon, adherent, in scars	2
Loss of hand, part of both	4
Loss of hearing, right ear	74
and adherent scar	1
and paralysis of facial nerve	5
Loss of hearing, left ear	77
and facial disfigurement	1
and loss of sight, one eye	1
and optic atrophy	1
and paralysis of facial nerve	1
Loss of hearing, both ears	29
Loss of hearing, partial	101
and amblyopia	1
and asphasia	1
and adherent scar	4
and loss of arm above elbow	2
and loss of sight, one eye	1
and paralysis of facial nerve	2
Loss of leg, right	14
and adherent scar	1
Loss of leg, left	22
and adherent scar	1
Loss of legs, both	2
Loss of leg at ankle, right	41
and adherent scar	5
Loss of leg at ankle, left	81
and ankylosis, bony, ankle	1
and ankylosis, bony, knee	1
and adherent scar	1
and loss of eye	1
Loss of legs at ankle, both	3
Loss of leg at knee, right	31
and ankylosis, fibrous, knee	1
and adherent scar	1
and fracture, faulty union	1
Loss of legs at knee, left	50
and ankylosis, fibrous, wrist	1
and adherent scar	1
and facial disfigurement	1
and loss of arm below elbow	1
Loss of legs at knees, both	1
Loss of leg, middle third, right	154
and ankylosis, fibrous, elbow	1
and ankylosis, fibrous, hip	1
and adherent scar	3
and loss of arm above elbow	1
and loss of arm below elbow	1
and loss of eye	1
and loss of leg at thigh	1
Loss of leg, middle third, left	157
and ankylosis, partial and deformities, knee	1
and adherent scar	4
and loss of foot	2
and paralysis of limb	1
Loss of legs, middle third, both	9
Loss of muscle	404
and amblyopia	2
and ankylosis, bony, hip	1
and ankylosis, bony, knee	1
and ankylosis, shoulder	1
and ankylosis, fibrous, ankle	2
and ankylosis, fibrous, elbow	11
and ankylosis, fibrous, knee	8
and ankylosis, fibrous, shoulder	13
and ankylosis, fibrous, wrist	1
and ankylosis, partial and deformities, ankle	6
and ankylosis, partial and deformities, elbow	4
and ankylosis, partial and deformities, hip	4
and ankylosis, partial and deformities, knee	7
and ankylosis, partial and deformities, shoulder	9
and adherent scar	86
and facial disfigurement	1
and fracture, faulty union	3
and glaucoma	2
and loss of arm above elbow	1
and loss of hearing, one side	1
and loss of leg below knee	1
and loss of leg at knee	2
and loss of leg at thigh	1
and loss of sight, one eye	1
and paralysis of limb	1
and pleurisy, chronic	1
and synovitis, chronic	1
and tendon, adherent in scar	1
Loss of ribs, part	2
Loss of scapula, right side	1
Loss of sight, right eye	89
and emblyopia	1
and ankylosis, fibrous, shoulder	1
and adherent scar	1
and facial disfigurement	3
and head disfigurement	1
and leucoma adherens	1
and loss of eye	2
and loss of hearing, one side	1
and optic atrophy	1
Loss of sight, left eye	71
and ankylosis, partial and deformities, elbow	1
and ankylosis, partial and deformities, hip	1
and adherent scar	2
and loss of eye	1
Loss of sight of both eyes	31
and ankylosis, partial and deformities, wrist	1
and facial disfigurement	1

TABLE 24.—*Associated physical disabilities (fatal cases excepted), resulting from battle injuries, in 19,768 officers and enlisted men, 1917–18*—Continued

Injuries	Number
Loss of teeth	74
and ankylosis, bony, elbow	1
and ankylosis, fibrous, hip	1
and adherent scar	15
and facial disfigurement	30
and fracture, nonunion	1
and loss of eye	1
and loss of hearing, one side	1
Loss of teeth, and loss of sight, one eye	1
Loss of testicle	32
and ankylosis, fibrous, knee	1
and ankylosis, partial and deformities, knee	1
and adherent scar	6
and facial disfigurement	1
and loss of eye	2
and loss of leg at thigh	2
and paralysis of limb	2
and tendon adherent in scars	1
Loss of thigh, upper third, right	122
and ankylosis, fibrous, ankle	1
and ankylosis, fibrous, shoulder	1
and ankylosis, partial and deformities, wrist	1
and adherent scar	3
and loss of arm above elbow	1
and loss of arm below elbow	2
Loss of thigh, upper third, left	95
and ankylosis, bony, elbow	1
and ankylosis, fibrous, elbow	1
and adherent scar	5
and fracture, faulty union	1
Loss of thighs, upper third, both	1
Loss of thigh, middle third, right	245
and ankylosis, fibrous, ankle	1
and adherent scar	3
and loss of leg below knee	2
and loss of leg at knee	2
Loss of thigh, middle third, left	245
and ankylosis, fibrous hip	1
and ankylosis partial and deformities, wrist	1
and arthritis, chronic, knee	1
and adherent scar	2
and flail joint, wrist	1
and fracture, faulty union	3
Loss of thighs, middle third, both	7
Loss of thigh, lower third, right	193
and amblyopia	1
and ankylosis, bony, knee	1
and ankylosis, fibrous, elbow	1
and ankylosis, fibrous, shoulder	1
and adherent scar	2
and loss of leg below knee	1
pleurisy, chronic	1
Loss of thigh, lower third, left	202
and amblyopia	1
and ankylosis, bony, knee	1
and ankylosis, fibrous, wrist	1
and ankylosis, partial and deformities, ankle	1
and ankylosis, partial and deformities, elbow	1
and adherent scar	3
and fracture, faulty union	1
and loss of arm above elbow	2
and loss of leg below knee	1
Loss of thighs, lower third, both	3
Lung, foreign bodies in	9
and ankylosis, partial and deformities, shoulder	1
and fracture, faulty union	1
Monoplegia	4
Nerve complication	646
and amblyopia	3
and aneurism	1
and ankylosis, bony, elbow	7
and ankylosis, bony, knee	2
and ankylosis, bony, wrist	2
and ankylosis, fibrous, ankle	9
and ankylosis, fibrous, elbow	37
and ankylosis, fibrous, hip	2
and ankylosis, fibrous, knee	10
and ankylosis, fibrous, shoulder	6
and ankylosis, fibrous, wrist	13
and ankylosis, partial and deformities, ankle	1
and ankylosis, partial and deformities, elbow	6
Nerve complication, and ankylosis, partial and deformities, hip	1
and ankylosis, partial and deformities, knee	2
and ankylosis, partial and deformities, shoulder	5
and ankylosis, partial and deformities, wrist	1
and aphasia	1
and adherent scar	53
and facial disfigurement	6
and fistula, urinary	1
and flail joint, elbow	1
and fracture, faulty union	16
and fracture, nonunion	3
and hernia	1
and loss of arm above elbow	2
and loss of eye	1
and loss of leg below knee	3
and loss of leg at knee	3
and loss of leg at thigh	1
and loss of sight, one eye	1
and tendon adherent in scars	1
and tendon severed and contracted	1
Nerves severed	3
Nerves severed and contracted	1
Neuritis following injury, arm, right	22
Neuritis following injury, arm, left	19
and ankylosis, fibrous, ankle	1
and ankylosis, fibrous, elbow	2
and adherent scar	1
and loss of eye	1
Neuritis following injury, arms, both	1
Neuritis following injury, forearm, right	1
and ankylosis, fibrous, wrist	1
Neuritis following injury, forearm, left	6
Neuritis following injury, leg, right	11
and ankylosis, fibrous, wrist	1
and tendon severed and contracted	1
Neuritis following injury, leg, left	12
and ankylosis, partial and deformities, ankle	1
Neuritis following injury, legs, both	1
Neuritis following injury, thigh, right	6
Neuritis following injury, thigh, left	1
Neuritis following injury, thigh, both	7
Optic atrophy	25
and ankylosis, partial and deformities, knee	1
and adherent scar	1
Osteomyelitis	224
and ankylosis, bony, elbow	1
and ankylosis, bony, shoulder	1
and ankylosis, fibrous, ankle	5
and ankylosis, fibrous, elbow	5
and ankylosis, fibrous, hip	2
and ankylosis, fibrous, knee	7
and ankylosis, fibrous, shoulder	2
and ankylosis, fibrous, wrist	3
and ankylosis, partial and deformities, ankle	1
and ankylosis, partial and deformities, knee	2
and ankylosis, partial and deformities, shoulder	1
and arthritis, chronic, ankle	1
and adherent scar	3
and facial disfigurement	1
and fistula, fecal	2
and fistula, urinary	1
and fracture, faulty union	9
and fracture, nonunion	3
and loss of arm above elbow	1
and loss of sight, one eye	1
and neuritis following injury	1
Paralysis, arm, right	187
and ankylosis, bony, ankle	1
and ankylosis, bony, shoulder	1
and ankylosis, fibrous, elbow	8
and ankylosis, fibrous, knee	1
and ankylosis, fibrous, shoulder	1
Paralysis and ankylosis, fibrous, wrist	2
and ankylosis, partial and deformities, elbow	5
and ankylosis, partial and deformities, knee	1
and ankylosis, partial and deformities, wrist	2
and aphasia	1
and adherent scar	5
and fracture, nonunion	1

TABLE 24.—*Associated physical disabilities (fatal cases excepted), resulting from battle injuries, in 19,768 officers and enlisted men, 1917–18*—Continued

Injuries	Number
Paralysis and hernia	1
and loss of sight, one eye	1
and paralysis, facial nerve	1
and paralysis of limb	2
Paralysis of arm, left	206
and ankylosis, bony, elbow	6
and ankylosis, bony, shoulder	1
and ankylosis, fibrous, elbow	12
and ankylosis, fibrous, wrist	3
and ankylosis, partial and deformities, elbow	1
and ankylosis, partial and deformities, shoulder	1
and ankylosis, partial and deformities, wrist	4
and adherent scar	7
and flail joint, elbow	1
and hernia	1
and paralysis of facial nerve	1
Paralysis of arms, both	2
Paralysis of arm from cord injuries, left	
and ankylosis, partial and deformities, elbow	1
Paralysis, facial nerve right side	25
and adherent scar	1
and fracture, nonunion	1
Paralysis, facial nerve, left side	22
and fracture, faulty union	1
Paralysis, foot, right	16
and adherent scar	1
and loss of leg at thigh	1
Paralysis, foot, left	26
Paralysis, hearing (auditory nerve)	2
and paralysis of facial nerve	1
Paralysis, leg, right	121
and ankylosis, fibrous, ankle	1
and ankylosis, fibrous, knee	4
and adherent scar	2
and fracture, faulty union	2
and loss of leg at thigh	1
Paralysis, leg, left	128
and ankylosis, fibrous, elbow	1
and ankylosis, fibrous, wrist	1
and ankylosis, partial and deformities, knee	1
and adherent scar	2
and loss of eye	1
Paralysis, legs, both	3
Paralysis, leg, from cord injuries, right	2
Paralysis, leg, from cord injuries, left	3
Paralysis, legs, from cord injuries, both	5
Paralysis, rectum, from cord injuries	1
Paralysis, speech	20
and ankylosis, fibrous, shoulder	1
and loss of arm above elbow	1
Paralysis, taste (gustatory nerve)	1
Paraplegia	29
and paralysis of limb, upper, from cord injuries	1
Pleurisy and adherent pleura	260
and ankylosis, fibrous, knee	1
and ankylosis, fibrous, shoulder	1
and ankylosis, partial and deformities, elbow	2
andankylosis, partial and deformities, shoulder	1
and adherent scar	13
and facial disfigurement	1
and fracture, faulty union	1
and hernia	2
Pleurisy and intestines, adhesion	1
and loss of eye	1
and loss of kidney, one	1
and loss of sight, one eye	1
and tendon adherent in scars	1
Rectum, loss of control of sphincter	6
Rectum, loss of portion	1
Scar adherent or painful	1,314
and ankylosis, bony, ankle	1
and ankylosis, fibrous, ankle	3
and ankylosis, fibrous, elbow	1
and ankylosis, fibrous, hip	2
and ankylosis, fibrous, knee	3
and ankylosis, fibrous, shoulder	1
and ankylosis, fibrous, wrist	1
and ankylosis, partial and deformities, ankle	3
and anklyosis, partial and deformities, elbow	6
and ankylosis, partial and deformities, hip	4
and ankylosis, partial and deformities, knee	3
and ankylosis, partial and deformities, shoulder	7
and ankylosis, partial and deformities, wrist	3
and facial disfigurement	2
and fracture, faulty union	3
and fracture, nonunion	1
and loss of eye	2
and loss of leg at hip	1
and loss of sight, one eye	1
and neuritis following injury	1
and synovitis, chronic	1
Spleen, infection	3
Stenosis, esophagus	1
Stenosis, rectum	3
and loss of arm above elbow	1
Stenosis, trachea	4
Swollen arm, left, from injured blood vessels	1
Swollen arms, both, from injured blood vessels	1
Swollen leg, right, from injured blood vessels	2
Swollen legs, both, from injured blood vessels	1
Synovitis, chronic, ankle, left	1
and ankylosis, partial and deformities, ankle	1
Synovitis, chronic, elbow, left	1
Synovitis, chronic, knee, right	22
Synovitis, chronic, knee, left	14
and ankylosis, partial and deformities, elbow	1
and adherent scar	1
and paralysis of limb, upper, from cord injuries	1
Synovitis, chronic, shoulder, right	2
Synovitis, chronic, shoulder, left	2
Synovitis, chronic, wrist, left	1
Tendon adherent in scars	22
and ankylosis, fibrous, ankle	1
and ankylosis, partial and deformities, ankle	1
and anklyosis, partial and deformities, knee	1
Tendon severed and contracted	65
and ankylosis, bony, wrist	1
and ankylosis, partial and deformities, ankle	1
and ankylosis, partial and deformities, wrist	1
and adherent scar	2
and paralysis of limb	1
Thrombophlebitis	3
Total	19,768

TABLE 25.—*Physical disabilities resulting from wounds (excepting fatal cases), by military agents, officers, and enlisted men, 1917–18; absolute numbers and percentage of each disability to the total number of cases wounded by the military agents* [a]

	Rifle		Shell and shrapnel		Hand grenade		Other gunshot		Others		Total	
Total admissions	20,420		51,226		880		75,125		5,886		153,537	
Results	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Ankle, right:												
Ankylosis, bony, of	3	0.01	13	0.03			6	0.01			22	0.01
Ankylosis, fibrous, of	16	.08	37	.07			41	.05			94	.06
Ankylosis, partial and deformities, of	39	.19	56	.11	1	0.11	42	.06	6	0.10	144	.09
Arthritis, chronic, of	1	.00	7	.01			3	.00	1	.02	12	.01
Flail joint of							1	.00			1	.00
Ankle, left:												
Ankylosis, bony, of	11	.05	21	.04			12	.02			44	.03
Ankylosis, fibrous, of	34	.17	44	.09	1	.11	51	.07	4	.07	134	.09
Ankylosis, partial and deformities, of	48	.24	74	.14			49	.07	2	.03	173	.11
Arthritis, chronic, of	4	.02	3	.01			1	.00	1	.02	9	.01
Flail joint of							1	.00			1	.00
Synovitis, chronic, of			2	.00							2	.00
Ankles, both:												
Ankylosis, bony, of			1	.00							1	.00
Ankylosis, fibrous, of	1	.00	2	.00			2	.00			5	.00
Ankylosis, partial and deformities, of	2	.01	3	.01							5	.00
Arthritis, chronic, of												
Ankle, s. n. s.:												
Ankylosis, bony, of	3	.01	2	.00							5	.00
Ankylosis, fibrous, of	11	.05	14	.03	1	.11	35	.05	1	.02	62	.04
Ankylosis, partial and deformities of	11	.05	38	.07	1	.11	10	.01			60	.04
Arthritis, chronic, of	1	.00	1	.00			2	.00			4	.00
Arm right:												
Contracture of	1	.00					2	.00			3	.00
Loss of, upper third	11	.05	71	.14	1	.11	18	.02	3	.05	104	.07
Loss of, above elbow	21	.10	115	.22	3	.34	14	.02	1	.02	154	.10
Loss of, at elbow	3	.01	15	.03			2	.00			20	.01
Neuritis, following injury	2	.01	2	.00	1	.11	17	.02			22	.01
Paralysis of	52	.25	95	.19	1	.11	71	.09	2	.03	221	.15
Paralysis of, from cord injuries												
Arm, left:												
Contracture of	1	.00	3	.01			1	.00			5	.00
Loss of, upper third	12	.06	80	.16	1	.11	16	.02	2	.03	111	.07
Loss of, above elbow	31	.15	112	.22			25	.03	3	.05	171	.11
Loss of, at elbow	3	.01	14	.03	2	.23	1	.00	1	.02	21	.01
Neuritis, following injury	4	.02	7	.01			12	.02	1	.02	24	.02
Paralysis of	73	.36	97	.19			72	.10	1	.02	243	.16
Paralysis of, from cord injuries			1	.00							1	.00
Swollen from injured blood vessels			1	.00							1	.00
Arms, both:												
Contracture of												
Loss of, upper third												
Loss of, above elbow												
Loss of, at elbow												
Neuritis, following injury							1	.00			1	.00
Paralysis of							2	.00			2	.00
Paralysis of, from cord injuries			3	.01							3	.00
Swollen from injured blood vessels			1	.00							1	.00
Arm, s. n. s.:												
Aneurism of (location not given)							1	.00			1	.00
Loss of, above elbow	2	.01	13	.03	2	.23	3	.00	1	.02	21	.01
Loss of, below elbow			7	.01	1	.11	1	.00			9	.01
Ear, right:												
Loss of			2	.00							2	.00
Loss of hearing of	4	.02	22	.04			7	.01	46	.78	79	.05
Ear, left:												
Loss of			5	.01			1	.00			6	.00
Loss of hearing of	1	.00	18	.04			8	.01	50	.85	77	.05
Ears, both:												
Loss of												
Loss of hearing of			3	.01					26	.44	29	.02
Ear, s. n. s.:												
Loss of			1	.00							1	.00
Loss of hearing, one side	3	.01	6	.01	2	.23			4	.07	15	.01
Paralysis, hearing (auditory nerve)	1	.00	1	.00			1	.00			3	.00
Partial loss of hearing	1	.00	21	.04			3	.00	85	1.44	110	.07
Elbow, right:												
Ankylosis, bony, of	10	.05	14	.03			17	.02	2	.03	43	.03
Ankylosis, fibrous, of	34	.17	47	.09			52	.07			133	.09
Ankylosis, partial and deformities, of	39	.19	73	.14	3	.34	57	.08	2	.03	174	.11
Arthritis, chronic, of	1	.00	2	.00			2	.00			5	.00
Flail joint of	2	.01					1	.00			3	.00

[a] Source of information: Medical records sent to the Surgeon General's Office.

TABLE 25.—*Physical disabilities resulting from wounds (excepting fatal cases), by military agents, officers, and enlisted men, 1917–18; absolute numbers and percentage of each disability to the total number of cases wounded by the military agents*—Continued

	Rifle		Shell and shrapnel		Hand grenade		Other gunshot		Others		Total	
Total admissions	20,420		51,226		880		75,125		5,886		153,537	
Results	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Elbow, left:												
Ankylosis, bony, of	4	0.02	19	0.04	1	0.11	14	0.02	1	0.02	39	0.03
Ankylosis, fibrous, of	26	.13	46	.09			54	.07	4	.07	130	.08
Ankylosis, partial, and deformities, of	53	.26	76	.15			42	.06	5	.08	176	.11
Arthritis, chronic, of			2	.00							2	.00
Flail joint of	2	.01	2	.00			1	.00			5	.00
Synovitis, chronic, of							1	.00			1	.00
Elbows, both:												
Ankylosis, bony, of												
Ankylosis, fibrous, of												
Ankylosis, partial, and deformities, of			2	.00							2	.00
Arthritis, chronic, of												
Elbow, s. n. s.:												
Ankylosis, bony, of	8	.04	4	.01			10	.01			22	.01
Ankylosis, fibrous, of	19	.09	26	.05			63	.08	2	.03	110	.07
Ankylosis, partial, and deformities, of	20	.10	42	.08	1	.11	12	.02	1	.02	76	.05
Flail joint of	1	.00	3	.01							4	.00
Eye, right:												
Loss of	13	.06	129	.25	6	.68	64	.09	6	.10	218	.14
Loss of sight of	10	.05	41	.08	5	.57	23	.03	10	.17	89	.06
Eye, left:												
Loss of	19	.09	115	.22	7	.80	77	.10	5	.08	223	.15
Loss of sight of	6	.03	41	.08			17	.02	2	.03	66	.04
Eyes, both:												
Loss of	3	.01	10	.02	1	.11					14	.01
Loss of sight of	1	.00	22	.04	1	.11	4	.01	2	.03	30	.02
Eye, s. n. s.:												
Loss of	1	.00	20	.04			7	.01			28	.02
Loss of sight, one eye	3	.01	19	.04			8	.01	1	.02	31	.02
Amaurosis			3	.01	1	.11					4	.00
Amblyopia	4	.02	19	.04	1	.11	16	.02	4	.07	44	.03
Cataract, traumatic	1	.00	21	.04	4	.45	3	.00	3	.05	32	.02
Face:												
Disfigurement of	25	.12	51	.10			60	.08	2	.03	138	.09
Paralysis of facial nerve (right side)	4	.02	13	.03			9	.01			26	.02
Paralysis of facial nerve (left side)	2	.01	12	.02			9	.01			23	.01
Paralysis of facial nerve (side not stated)	5	.02	11	.02			6	.01	1	.02	23	.01
Femur, right, false joint of							1	.00			1	.00
Fibula, false joint of right side							1	.00			1	.00
Fibula and tibia, false joint of, right side							1	.00			1	.00
Foot, right:												
Flat foot, traumatic			2	.00			1	.00			3	.00
Loss of	2	.01	6	.01	1	.11	4	.01			13	.01
Loss of part of	25	.12	65	.13	1	.11	49	.07	2	.03	142	.09
Paralysis of	4	.02	7	.01			6	.01	1	.02	18	.01
Foot, left:												
Flat foot, traumatic	1	.00	1	.00			1	.00			3	.00
Loss of	1	.00	5	.01			2	.00			8	.01
Loss of part of	25	.12	63	.12			52	.07	4	.07	144	.09
Paralysis of	1	.00	16	.03			9	.01			26	.02
Feet, both:												
Flat foot, traumatic			1	.00			1	.00			2	.00
Loss of			1	.00							1	.01
Loss of part of			2	.00			1	.00			3	.00
Foot, s. n. s.:												
Ankylosis of one or more joints	59	.29	103	.20			61	.08	2	.03	225	.15
Loss of			2	.00							2	.00
Forearm, right:												
Loss of, above wrist	9	.04	56	.11	14	1.59	5	.01	1	.02	85	.06
Neuritis, following injury			2	.00							2	.00
Forearm, left:												
Loss of, above wrist	14	.07	94	.18	16	1.82	12	.02	1	.02	137	.09
Neuritis, following injury			1	.00			2	.00	1	.02	4	.00
Forearms, both, loss of, above wrist			1	.00	2	.23					3	.00
Hand, right:												
Loss of all	1	.00	2	.00	2	.23	1	.00			6	.00
Loss of at wrist	1	.00	8	.02	2	.23					11	.01
Loss of part of	111	.54	263	.51	7	.80	224	.30	9	.15	614	.40
Hand, left:												
Loss of all			7	.01	3	.34	2	.00			12	.01
Loss of at wrist	1	.00	2	.00	7	.80	5	.01			15	.01
Loss of part of	182	.89	325	.63	15	1.70	351	.47	12	.20	885	.58

TABLE 25.—*Physical disabilities resulting from wounds (excepting fatal cases), by military agents, officers, and enlisted men, 1917–18; absolute numbers and percentage of each disability to the total number of cases wounded by the military agents*—Continued

	Rifle		Shell and shrapnel		Hand grenade		Other gunshot		Others		Total	
Total admissions	20,420		51,226		880		75,125		5,886		153,537	
Results	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Hands, both:												
Loss of all			1	0.00							1	0.00
Loss of, at wrist												
Loss of, part of			3	.01					1	0.02	4	.00
Hand, s. n. s.:												
Ankylosis of one or more joints	173	0.85	335	.65	6	0.68	244	0.32	9	.15	767	.50
Loss of			2	.00	1	.11	1	.00			4	.00
Head, disfigurement of			3	.01			3	.00	1	.02	7	.00
Hip, right:												
Ankylosis, bony, of	1	.00	3	.01			1	.00			5	.00
Ankylosis, fibrous, of	5	.02	11	.02			14	.02			30	.02
Ankylosis, partial and deformities of	13	.06	9	.02			11	.01			33	.02
Arthritis, chronic, of			1	.00			1	.00	1	.02	3	.00
Hip, left:												
Ankylosis, bony, of			1	.00			4	.01			5	.00
Ankylosis, fibrous, of	9	.04	12	.02			13	.02	1	.02	35	.02
Ankylosis, partial and deformities of	10	.05	20	.04	1	.11	6	.01	1	.02	38	.02
Arthritis, chronic, of	1	.00	1	.00							2	.00
Flail joint of			1	.00							1	.00
Hips, s. n. s.:												
Ankylosis, bony, of	2	.01					3	.00			5	.00
Ankylosis, fibrous, of	4	.02	7	.01			10	.01	1	.02	22	.01
Ankylosis, partial and deformities of	4	.02	11	.02			9	.01			24	.02
Intestines:												
Adhesions of	11	.05	10	.02			5	.01	1	.02	27	.02
Fistula of			1	.00							1	.00
Obstruction of			1	.00			1	.00			2	.00
Partial loss of			2	.00							2	.00
Kidney, loss of, one sequelæ			3	.01			3	.00			6	.00
Knee, right:												
Ankylosis, bony, of	4	.02	17	.03			20	.03			41	.03
Ankylosis, fibrous, of	50	.24	67	.13	2	.23	63	.08	3	.05	185	.12
Ankylosis, partial and deformities of	49	.24	109	.21			61	.08	7	.12	226	.15
Arthritis, chronic, of	5	.02	10	.02			5	.01	1	.02	21	.01
Flail joint of			1	.08			1	.00			2	.00
Synovitis of	4	.02	8	.02			7	.01	2	.03	21	.01
Knee, left:												
Ankylosis, bony, of	12	.06	26	.05	1	.11	11	.01			50	.03
Ankylosis, fibrous, of	30	.15	61	.12			52	.07	6	.10	149	.10
Ankylosis, partial and deformities of	48	.24	104	.20	1	.11	55	.07	3	.05	211	.14
Arthritis, chronic of	2	.01	4	.01			7	.01	2	.03	15	.01
Flail joint of	1	.00	1	.00							2	.00
Synovitis, chronic, of	2	.01	7	.01	1	.11	6	.01	1	.02	17	.01
Knees, both:												
Ankylosis, bony, of	2	.01	2	.00							4	.00
Ankylosis, fibrous, of									1	.02	1	.00
Ankylosis, partial and deformities of	2	.01	7	.01			4	.01			13	.01
Arthritis, chronic, of			2	.00							2	.00
Knee, s. n. s.:												
Ankylosis, bony, of	5	.02	9	.02			3	.00			17	.01
Ankylosis, fibrous, of	22	.11	30	.06	1	.11	39	.05	2	.03	94	.06
Ankylosis, partial and deformities of	6	.03	41	.08	1	.11	7	.01	1	.02	56	.04
Arthritis, chronic, of			3	.01							3	.00
Leg, right:												
Aneurism of	1	.00									1	.00
Contracture of	1	.00	5	.01			1	.00			7	.00
Loss of	3	.01	9	.02			3	.00			15	.01
Loss of, at ankle	7	.03	30	.06	2	.23	7	.01			46	.03
Loss of, at knee	8	.04	21	.04	1	.11	3	.00	1	.02	34	.02
Loss of, middle third	30	.15	97	.20	4	.45	29	.04	3	.05	163	.11
Neuritis of, following injury	2	.01	3	.01			7	.01	1	.02	13	.01
Paralysis of	29	.14	59	.12	1	.11	39	.05	3	.05	131	.09
Paralysis of, from cord injuries			1	.00			1	.00			2	.00
Swollen from injured blood vessels	1	.00					1	.00			2	.00
Leg, left:												
Contracture of	2	.01	7	.01			2	.00	1	.02	12	.01
Loss of	2	.01	17	.03	1	.11	3	.00			23	.01
Loss of, at ankle	15	.07	55	.11	1	.11	12	.02	2	.03	85	.06
Loss of, at knee	10	.05	38	.07			6	.01			54	.04
Loss of, middle third	26	.13	114	.22			22	.03	3	.05	165	.11
Neuritis of, following injury	2	.01	2	.00			9	.01			13	.01
Paralysis of	27	.13	50	.10	1	.11	55	.07	1	.02	134	.09
Paralysis of, from cord injuries	1	.00					1	.00	1	.02	3	.00

TABLE 25.—*Physical disabilities resulting from wounds (excepting fatal cases), by military agents, officers, and enlisted men, 1917–18; absolute numbers and percentage of each disability to the total number of cases wounded by the military agents*—Continued

	Rifle		Shell and shrapnel		Hand grenade		Other gunshot		Others		Total	
Total admissions	20,420		50,226		880		75,125		5,886		153,537	
Results	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Legs, both:												
Contracture of							2	0.00			2	0.00
Loss of			2	0.00							2	.00
Loss of, at ankle			2	.00					1	0.02	3	.00
Loss of, at knee							1	.00			1	.00
Loss of, middle third			7	.01			2	.00			9	.01
Neuritis, following injury							1	.00			1	.00
Paralysis of			2	.00			1	.00			3	.00
Paralysis of, from cord injury	1	0.00	2	.00			2	.00			5	.00
Swollen from injured blood vessels							1	.00			1	.00
Leg, s. n. s.:												
Contracture of limb	1	.00									1	.00
Loss of, below knee			13	.03			7	.01	1	.02	21	.01
Loss of, at hip			2	.00							2	.00
Loss of, at knee			8	.02			3	.00	1	.02	12	.01
Loss of, at thigh	4	.02	12	.02			1	.00			17	.01
Paralysis of limb	7	.03	17	.03			8	.01	1	.02	33	.02
Paralysis of, from cord injuries			1	.00							1	.00
Ligament, relaxation of			2	.00			3	.00	10	.17	15	.01
Lower extremity, atrophy of muscle of	30	.15	52	.10			36	.05	2	.03	120	.08
Lung, foreign bodies in	1	.00	10	.02							11	.01
Muscle:												
Hernia of	1	.00	10	.02			4	.01			15	.01
Loss of	91	.45	334	.65	6	0.68	145	.19	1	.02	577	.38
Nerves:												
Complication of	131	.64	69	.53	3	.34	434	.58	7	.12	844	.55
Severed	2	.01	1	.00							3	.00
Severed and contracted			1	.00			1	.00			2	.00
Ribs, loss of, part			2	.00							2	.00
Rectum:												
Paralysis of, from cord injuries							1	.00			1	.00
Loss of control of sphincter	2	.01	3	.01			1	.00	1	.02	7	.00
Loss of portion			1	.00							1	.00
Stenosis of			3	.01	1	.11					4	.00
Scapula, loss of right side	1	.00									1	.00
Shoulder, right:												
Ankylosis, bony, of	11	.05	9	.02			6	.01			26	.02
Ankylosis, fibrous, of	16	.08	42	.08			41	.05			99	.06
Ankylosis, partial and deformities of	29	.14	73	.14	2	.23	33	.04	3	.05	140	.09
Arthritis, chronic, of	1	.00	1	.00			1	.00			3	.00
Flail joint of			1	.00			5	.01			6	.00
Synovitis of			1	.00			1	.00			2	.00
Shoulder, left;												
Ankylosis, bony, of	1	.00	9	.02			7	.01			17	.01
Ankylosis, fibrous, of	23	.11	39	.08			39	.05	1	.02	102	.07
Ankylosis, partial and deformities of	30	.15	83	.16			31	.04	2	.03	146	.10
Arthritis, chronic, of			2	.00							2	.00
Flail joint of	1	.00	1	.00			1	.00			3	.00
Synovitis of							2	.00			2	.00
Shoulders, both:												
Ankylosis, partial and deformities of			1	.00							1	.00
Shoulder, s. n. s.:												
Ankylosis, bony, of	1	.00	6	.01			4	.01			11	.01
Ankylosis, fibrous, of	11	.05	19	.04			24	.03			54	.04
Ankylosis, partial and deformities of	13	.06	37	.07			9	.01			59	.04
Arthritis, chronic, of							1	.00			1	.00
Flail joint of	1	.00	1	.00			1	.00			3	.00
Spine:												
Ankylosis of	8	.04	30	.06			16	.02	10	.17	64	.04
Arthritis of			1	.00					2	.03	3	.00
Spleen, infection of							3	.00			3	.00
Teeth, loss of	38	.19	43	.08			40	.05	2	.03	123	.08
Tendon:												
Adherent in scars	8	.04	20	.04			9	.01	1	.02	38	.02
Severed and contracted	16	.08	37	.07	1	.11	26	.03	1	.02	81	.05
Testicle, loss of	9	.04	26	.05	1	.11	11	.01	1	.02	48	.03
Thigh, right:												
Loss of, upper third	32	.16	81	.16	1	.11	16	.02	1	.02	131	.09
Loss of, middle third	38	.19	174	.34	5	.57	32	.04	4	.07	253	.16
Loss of, lower third	38	.19	140	.27			21	.03	2	.03	201	.13
Neuritis, following injury	1	.00	3	.01			2	.00			6	.00
Thigh, left:												
Loss of, upper third	21	.10	66	.13	2	.23	14	.02			103	.07
Loss of, middle third	46	.23	176	.34			31	.04	1	.02	254	.17
Loss of, lower third	40	.20	150	.29			24	.03			214	.14
Neuritis, following injury							1	.00			1	.00

TABLE 25.—*Physical disabilities resulting from wounds (excepting fatal cases), by military agents, officers, and enlisted men, 1917–18; absolute numbers and percentage of each disability to the total number of cases wounded by the military agents*—Continued

	Rifle		Shell and shrapnel		Hand grenade		Other gunshot		Others		Total	
Total admissions	20,420		51,226		880		75,125		5,886		153,537	
Results	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Thighs, both:												
Loss of, upper third	1	0.00									1	0.00
Loss of, middle third	2	.01	4	0.01			1	0.00			7	.00
Loss of, lower third	1	.00	1	.00			1	.00			3	.00
Neuritis of, following injury	1	.00	4	.01			1	.00			6	.00
Thigh, s. n. s., aneurism (location not stated)					1	0.11					1	.00
Trachea, stenosis of	2	.01	2	.00			1	.00			5	.00
Upper extremity, atrophy of muscle of	37	.18	60	.12			37	.05	2	0.03	136	.09
Wrist, right:												
Ankylosis, bony, of	3	.01	7	.01			3	.00			13	.01
Ankylosis, fibrous, of	14	.07	25	.05			22	.03	1	.02	62	.04
Ankylosis, partial, and deformities of	10	.05	42	.08	1	.11	22	.03	2	.03	77	.05
Arthritis, chronic, of			2	.00					1	.02	3	.00
Wrist, left:												
Ankylosis, bony, of	5	.02	4	.01			7	.01	1	.02	17	.01
Ankylosis, fibrous, of	21	.10	24	.05			29	.04			74	.05
Ankylosis, partial and deformities of	20	.10	46	.09			34	.05	2	.03	102	.07
Arthritis, chronic, of			3	.01			1	.00			4	.00
Synovitis, chronic, of							1	.00			1	.00
Wrists, both:												
Ankylosis, fibrous, of							1	.00			1	.00
Arthritis, chronic, of			1	.00							1	.00
Wrist, s. n. s.:												
Ankylosis, bony, of	2	.01	4	.01			4	.01			10	.01
Ankylosis, fibrous, of	9	.04	17	.03	1	.11	29	.04	1	.02	57	.04
Ankylosis, partial and deformities of	14	.07	36	.07			12	.02	1	.02	63	.04
Arthritis, chronic, of			1	.00							1	.00
Aneurism:												
Not specified							2	.00			2	.00
Abdominal			1	.00							1	.00
Aorta, thoracic	2	.01	1	.00							3	.00
Arteriovenus			2	.00			3	.00			5	.00
Artery, axillary	1	.00									1	.00
Artery, carotid							1	.00			1	.00
Artery, femoral	1	.00					2	.00			3	.00
Aphasia	2	.01	2	.00			3	.00			7	.00
Bone tissue, loss of	102	.50	191	.37	2	.23	175	.23	6	.10	476	.31
Bulbar palsy							1	.00			1	.00
Bronchitis, chronic	14	.07	36	.07	1	.11	30	.04	28	.48	109	.07
Cardiac dilatation							1	.00			1	.00
Chest, deformities of, from injury	1	.00	4	.01			1	.00	1	.02	7	.00
Conjunctivitis, chronic			1	.00					1	.02	2	.00
Convalescent from wounds	134	.66	280	.55	6	.68	149	.20	1	.02	570	.37
Deformities, larynx			1	.00							1	.00
Epilepsy			3	.01			2	.00			5	.00
Epilepsy, Jacksonian			1	.00			1	.00			2	.00
Fistula:												
Fecal	2	.01	4	.01			5	.01	1	.02	12	.01
Other	2	.01	3	.01							5	.00
Retrovesical			1	.00							1	.00
Retrouretal							1	.00			1	.00
Urinary	1	.00	1	.00			2	.00			4	.00
Fracture:												
Deforming	160	.78	278	.54	2	.23	172	.23	15	.25	627	.41
Faulty union	93	.46	161	.31	1	.11	197	.26	10	.17	462	.30
Old, ununited	15	.07	32	.06			15	.02	1	.02	63	.04
Glaucoma, secondary	1	.00	1	.00			1	.00			3	.00
Heel, painful	1	.00					1	.00			2	.00
Hemiplegia	8	.04	16	.03			16	.02	1	.02	41	.03
Hernia:												
Cerebral			2	.00			1	.00			3	.00
Ventral	5	.02	9	.02			6	.01			20	.01
Not specified	2	.01	4	.01							6	.00
Laryngitis, chronic			2	.00			2	.00	1	.02	5	.00
Leucoma			3	.01	2	.23	2	.00	1	.02	8	.01
Leucoma, adherent	1	.00									1	.00
Monoplegia							4	.01			4	.00
Neuritis, n. s	2	.01					2	.00			4	.00
Optic atrophy	4	.02	20	.04	3	.34	4	.01			31	.02
Osteomyelitis	48	.24	101	.20	2	.23	122	.16	2	.03	275	.18
Paraplegia	7	.03	11	.02			10	.01	2	.03	30	.02
Pleurisy and adherent pleura	77	.38	103	.20			65	.09			245	.16
Speech, paralysis of	6	.03	5	.01			5	.01	1	.02	17	.01
Scar, adherent or painful	386	1.89	1,041	2.03	24	2.73	425	.57	13	.22	1,889	1.23

TABLE 25.—*Physical disabilities resulting from wounds (excepting fatal cases), by military agents, officers, and enlisted men, 1917–18; absolute numbers and percentage of each disability to the total number of cases wounded by the military agents*—Continued

	Rifle		Shell and shrapnel		Hand grenade		Other gunshot		Others		Total	
Total admissions	20,420		51,226		880		75,125		5,886		153,537	
Results	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Sacroiliac ankylosis	1	.00	4	.01			2	.00	3	.05	10	.01
Synovitis, chronic, n. s.	1	.00	2	.00					1	.02	4	.00
Taste, paralysis of			1	.00							1	.00
Temporomaxillary ankylosis	3	.01	4	.01			6	.01			13	.01
Thrombophlebitis			2	.00			1	.00			3	.00
Others	1	.00	6	.01			2	.00	5	.08	14	.01
Total	3,739	18.30	9,060	17.69	213	24.20	5,579	7.43	549	9.33	19,140	12.47

NOTE.—S. n. s. signifies, "side not specified." N. s. signifies, "not specified."

PHYSICAL DISABILITIES BY MILITARY AGENTS

The number of physical disabilities which resulted from military agents was 19,140 (not men, but disabilities). It should be noted that we are here speaking of disabilities, and not of individual men, although the number of the disabilities is less than the number of men disabled, which is shown in Table 24 as 19,768. The excess is due to the inclusion there of men disabled by gas. If disabilities from the latter were included in Table 25, the total would be 21,696.

The percentage of disabilities from the various gunshot missiles was as follows: Shell and shrapnel, 17.69; hand grenade, 24.20; rifle, 18.30; other gunshot missiles, 7.43. From this we see that the highest proportion of disabilities resulted from the artillery missiles, with the exception of the hand grenades, where the number of cases was small.

CHAPTER IV

SURGERY AT THE FRONT

GENERAL CONSIDERATIONS

Medical Department plans for the surgical treatment of wounded at the front prior to our entrance into the World War, were essentially conservative.[1] They were based almost purely upon a hypothetical war of movement; therefore, the maintenance of mobility of divisional Medical Department organizations (dressing stations, field hospitals) and of evacuation hospitals, which were intermediate facilities, was of paramount importance. The evacuation of wounded, with notable exceptions which will be referred to later, was to be of primary consideration. In effect, the provisions in question, from the front rearward, to and including evacuation hospitals, were as follows: With line organizations—regiments, trains, etc.; the sanitary train, comprising dressing stations, field hospitals; evacuations hospitals.[2]

The Medical Department equipment, provided for a regiment or other line organization operating as a part of a division, consisted of first-aid packets, individual equipment of the Medical Department personnel, and the combat equipment.[3] In combat the duties that were to devolve on the sanitary personnel were to render first aid to the wounded; to establish and operate an aid station, and to collect wounded thereat; to direct the trivially wounded to return to the line, and to direct others with slight wounds to the station for the slightly wounded; and in exceptional cases to transport the severely wounded to the dressing stations.[4] Since the regimental medical personnel was to keep in touch with the regiment, no elaborate or fixed arrangements for the care and treatment of wounded were to be undertaken. Such treatment was to be imited ordinarily to first-aid and to the readjustment of dressings which previously had been applied either by medical personnel in advance of the dressing station, or by the wounded themselves.

Activities at the dressing station (to be established by the ambulance company section of the sanitary train) were to be carried on under the following departments:[5] Dispensary; kitchen; receiving and forwarding; slightly wounded; seriously wounded. Here, only such operations were to be performed as might be immediately required to save life or to render the patients fit for further transportation. Permanent occlusive dressings were to be applied, time permitting. The rules generally to be followed were that no operative or other nterference should be attempted under conditions unfavorable for asepsis or antisepsis, and that no wounded for whom transportation might be available should be delayed at the dressing station.

Since the function of the field hospital was to keep in touch with the combatant organizations, and to provide care and treatment as far as practicable for the sick and wounded of the division until taken care of by the sanitary

service of the line of communications, it could meet these conditions only when relieved promptly by medical units to its rear. Under ordinary battle conditions surgical operations were to be such only as might be needed to fit patients for transportation to the rear.[6]

In the evacuation hospitals, which were to relieve the field hospitals of their sick and wounded, the treatment of wounded was to be hardly more extensive than that at field hospitals, viz, emergency operations and better preparation for transport. Particularly was this true during battle when many wounded would be received. On the other hand, in the absence of many wounded and of the probability of an early move, complete surgical treatment was permissible.[7]

When we entered the World War its character had for long been static; it was possible, therefore, to partially immobilize the units mentioned above. Such being the case, evacuation of the wounded became less of an urgent necessity from a purely military standpoint and more or less subservient to the interests of the patients themselves. And whereas formerly no surgical intervention was to be practiced farther forward than base hospitals, except in times of quiet, it was found now that definitive treatment could not ordinarily be left until patients could reach hospitals in the rear; it had to be practiced in stages, and the preliminary stages must be accomplished as early and as near the front as possible. At this time, in contradistinction to former wars when rifle wounds were over 80 per cent and shell wounds in the neighborhood of 13 or 14 per cent,[8] wounds caused by shell fragments were almost the rule (80 per cent); bullet wounds were rare.[9] Since the wounds caused by the shell splinters were invariably infected with organisms whose period of incubation was extremely short, most severe complications, if not fatality, were to be expected unless surgical intervention could be practiced within a relatively few hours of the receipt of injury. Thus, though our earliest plans for surgery at the front had to conform to static warfare, this changed to open warfare at a time when our greatest numbers were involved, and though some general modifications in surgical treatment were possible, for example, delayed surgical treatment until patients in some instances could reach base hospitals located near the front, the treatment per se was essentially the same.

GENERAL TREATMENT OF WOUNDS

The subject of wound treatment at the front obviously must include all procedures from the application of the first-aid dressing on the battle field to the final dressing immediately preceding the evacuation of the patient from the zone of the advance to the base. The successive stages in which such treatment was given involved some or all of the following places or stations through which wounded men passed from the front line rearward: On the battle field, company aid stations, battalion aid stations, regimental aid stations, advanced dressing stations, dressing stations, field hospitals, mobile hospitals, evacuation hospitals.

While it is essential in the interests of completeness to consider the subject, in this chapter, from the viewpoint of the above enumerated places and stations, thus repeating some things which are given in greater detail in another

volume of this history,[a] it is not the purpose to dicuss herein special surgical treatment, except in so far as is necessary. Such special treatment is made the subjects of separate subsequent chapters.

ON THE BATTLE FIELD

Each soldier was provided, as a part of his individual equipment, with either a Medical Department regulation first-aid packet or a front packet. In addition, Medical Department enlisted men, assigned to line organizations, carried a liberal quantity of these packets and iodine swabs. The first-aid packet, in a metal case 4 by 2¼ by 1 inch, comprised 2 gauze bandages, 4 by 84 inches, 2 gauze compresses, 3½ by 3½ inches, 2 safety pins, and directions for application.[10]

FRONT PACKETS

The following extract not only describes the kinds of front packets adopted for the American Expeditionary Forces, but contains as well directions as to the use of these packets:[11]

The dressings here described are intended for use in the dressing stations of the units in combat, in the field hospitals, the mobile hospitals, the evacuation hospitals, and the base hospitals.

Surgical dressings should protect the wounded man from: (1) Trauma to his wounds; (2) loss of blood; (3) secondary infection, and should be so applied as to add to his comfort during treatment and transportation.

In the manufacture of these dressings it is not essential that absolute accuracy in measurements be observed.

Front packets.—These packets are to be used by medical units in the area of combat. The outer covering is coated with paraffin to protect the contents of the packet against wet and vesicant gases.

I. PACKET NO. 1. RED LABEL

For small wounds.

This packet contains the following supplies, the outer wrapper of which is made of kraft paper dipped in paraffin. It is marked with two red bands.

On opening the outer covering there will be found: (1) 1 unbleached muslin bandage, 4 to 5 inches by 5 yards, cut on the bias; 2 safety pins, 1½ inches long, attached to the bandage. (2) A muslin bag, which opens at one end. This bag contains sterile dressings wrapped in a special paper. These dressings should be handled with as much care as possible to prevent contamination.

The sterile dressings comprise: (1) 4 gauze sponges or wipes, 4 inches by 4½ inches, for covering the wound; (2) 1 absorbent pad, 4 inches by 6 inches; (3) 1 gauze bandage, 4 inches wide.

With these supplies the wound should be covered and the absorbent pad held in place by the gauze bandage. Finally the muslin bandage should be applied and firmly fastened with the safety pins to make the dressing secure or to apply the proper splint.

II. PACKET NO. 2. WHITE LABEL

For medium-sized wounds.

This packet contains the following supplies, the outer wrapper of which is made of kraft paper dipped in paraffin. It is marked with two white bands.

On opening the outer covering there will be found: (1) 1 unbleached muslin bandage, 4 to 5 inches by 5 yards, cut on the bias; 2 safety pins, 1½ inches long, are attached to the bandage. (2) A muslin bag, which opens at one end. This bag contains sterile dressings

[a] Vol. VIII, Field Operations, American Expeditionary Forces.

wrapped in a special paper. These dressings should be handled with as much care as possible to prevent contamination.

The sterile dressings comprise: (1) 4 gauze sponges or wipes, 4 inches by 4½ inches; (2) 1 absorbent pad, 6 inches by 8 inches; (3) 1 gauze bandage, 4 inches wide.

With these supplies, the wound should be covered and the absorbent pad held in place by the gauze bandage. Finally the muslin bandage should be applied and firmly fastened with the safety pins to make the dressing secure or to apply the proper splint.

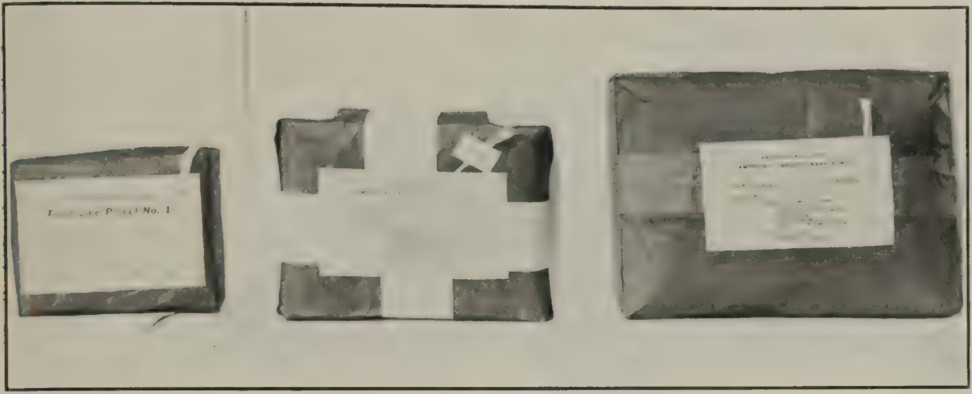

FIG. 78.—Front-line packages Nos. 1, 2, and 3

FIG. 79.—First-aid outfit, complete

III. PACKET NO. 3. BLUE LABEL

For large wounds.

This packet contains the following supplies, the outer wrapper of which is made of kraft paper dipped in paraffin. It is marked with two blue bands.

On opening the outer covering there will be found: (1) 2 unbleached muslin bandages, 4 to 5 inches by 5 yards, cut on the bias; 2 safety pins 1½ inches long are attached to each bandage. (2) A muslin bag which opens at one end. This bag contains sterile dressings

wrapped in a special paper. These dressings should be handled with as much care as possible to prevent contamination.

The sterile dressings comprise: (1) 6 gauze compresses, 4 inches by 8 inches; (2) 1 absorbent pad, 10 by 18 inches; (3) 1 gauze bandage, 6 inches wide.

With these supplies, the wound should be covered and the absorbent pad held in place by the gauze bandage. Finally the muslin bandage should be applied and firmly fastened with the safety pins to make the dressing secure or to apply the proper splint.

It was impressed upon the soldier that the first-aid dressing was for his individual use in the event of injury, and frequent inspections were made to insure the constant possession of these packets. Medical Department enlisted men assigned to battalions carried usually in a duffel bag or gunny sack a liberal quantity of these packets and iodine swabs. This was important because of the frequency of multiple wounds and of the frequent lack of a packet on the person of the wounded by reason of its having been either lost, or, contrary to instructions, applied to a wounded comrade. Directions for the use of these dressings were given each combatant as a routine, and all Medical Department personnel were fully instructed in their application. In the light of our experience particular attention in this instruction should be directed to: (*a*) The importance of applying the dressing directly to the wound without the interposition of either outer garments or underclothing. (*b*) The avoidance of the removal of clothing not necessary to uncover the wounds, thus lessening a tendency to shock. (*c*) The danger incident to tightly packing a wound in the mistaken belief that complete cessation of hemorrhage is necessary. (*d*) Contraction of a dry dressing and bandage after their saturation with blood, water, or perspiration, with consequent circulatory interference, discomfort, and pain. Hemorrhage from fractured bone, lacerated muscles, or blood vessels of a limb inevitably results in swelling, and the earlier the application of a dressing and bandage to such a wound the greater should be the allowance for the consequent swelling. A dressing and bandage should be sufficiently snug to retain its position during transportation without causing constriction. (*e*) The desirability of immobilization of a wounded area, even in the absence of fracture. Rest of damaged tissue enables nature to marshal her defensive forces for the localization of infection, and the degree of immobilization of a wound area, even though only the soft tissues are involved, largely determines

FIG. 80.—First-aid bandage, with hooks and tape

FIG. 81.—Immobilization of upper extremity against patient's side

FIG. 82.—Thomas leg splint applied over clothing; traction made on shoe

the chances of the wounds healing without infection or with only localized infection. Nothing tends to disseminate infective material, particularly sand, dirt, particles of clothing, and the like, more rapidly than muscle spasm in the vicinity of a wound, and the development of gas gangrene after an apparently thorough débridement of lacerated tissues is due, in all probability, to a dissemination of minute foreign particles beyond the zone of débridement. The immobilization of wound areas in regions having multiple layers of muscle with intervening planes of fascia, particularly the thigh and legs, should be equally thorough in both the presence and absence of fracture. (*f*) The imperativeness of making no attempt to cleanse a wound on the battle field, because of the insufficiently trained personnel, the time element, and the lack of essential facilities. A wound left alone rather than half cleansed is far more safe. Iodine, if available, was to be applied to the edges of the wound, but was not to be applied within a deep wound, since nothing could be accomplished in the way of antisepticizing, and the danger of setting up a new hemorrhage by dislodging a blood clot was to be in mind. (*g*) Immobilization, to begin on the battle field when possible, by the use of simple straight or improvised splints. The use of the Thomas splint for either arm or leg on the battle field is rarely possible because of the time required for its proper adjustment and the impracticability of carrying on the person. Also, the Thomas splint is essentially a traction splint and does not afford complete immobilization unless reinforced with one or more straight splints. In the absence of any splinting material, for the purpose of transportation the upper extremity may be readily immobilized by bandaging or strapping it against the body, and the lower extremity by splinting against the opposite limb. Efficient splinting invariably includes the joints above and below the wound, whether or not fracture is present. Only by including these joints will muscle contraction cease

FIG. 83.—First aid in trench warfare

and foreign particles remain in situ. Splints should never prevent free access to the wound and should be applied so as to permit changing the field dressing at the battalion aid station without removal of the splint. Adequate padding for all splints must be improvised on the battle field, and this is especially necessary over bony prominences, such as the elbow, wrist, iliac crest, great trochanters, femoral condyles, malleoli, and in the axilla. For this purpose articles of clothing, packing, leaves, grass, and the like can be utilized. The improper observance of this cardinal point predisposes to shock and the development of pressure necrosis of overlying tissues.

The idea was to apply first aid immediately at the place where the wound was incurred, either by Medical Department personnel on duty with organizations in the front line or serving as litter bearers, or by litter bearers detailed from the line who were instructed in elementary first aid. Such application was usual in trench warfare, in which the casualties frequently occurred in the trench itself from desultory enemy fire, and special cover for dressing was not always essential. This applied also to a less extent to open warfare in periods of quiescence, but at times of great activity it was often impossible to apply dressings before transporting the patient to a company or battalion aid station, or even to reach the wounded for varying periods of time.

THE COMPANY AID STATION

In some instances stations subsidiary to battalion aid stations were established in the front line for each company, conducted by two dressers assigned from the battalion medical personnel.[12] At these company aid stations emergency treatment was given the wounded brought thereto usually by line litter bearers.

Such stations were more commonly used in trench warfare when it was possible to keep a small supply of surplus dressings and even splints, and sometimes a battalion medical officer took station there; but in open warfare the only available dressings usually were those carried on the person, and often the only shelter was that afforded by a shell hole, consequently the wounded habitually were borne to the battalion aid station.

THE BATTALION AID STATION

With the increased strength of our battalions, the battalion aid station closely approximated in size the regimental aid station as prescribed in the Manual for the Medical Department, the regimental aid station then not being generally employed.[12]

In trench warfare, battalion aid stations usually were located in dugouts in the support line, 250 to 1,000 yards in rear of the front line, on or near an evacuation trench.[12] The equipment, in addition to that enumerated in supply tables for a battalion, included at least two Thomas splints, and a shock table for warming patients. Light was supplied by simple petroleum lamps, and in some electricity was present. Cooking was done below, when possible, coke or any available fuel being used and ventilators having dampers for excluding gas, led to the surface. Often the food was prepared in a separate adjacent

dugout or improvised lean-to and in some sectors food was brought up in marmites at night time. The source of heat was small wood-burning stoves. The supplies were usually brought up by the battalion medical carts or other vehicles, and replacements were made through a system of exchange by ambulances, trucks, or litter bearers. The supplies habitually included stimulants and ample facilities and material for the preparation of hot liquid foods, and other articles of food were also stocked, as often in periods of intense bombardment patients could not be evacuated until after dark, and preparedness for the bestowal of all possible attention, short of surgical intervention, upon the wounded for a varying number of hours was necessary.[12]

FIG. 84.—Administering a hot drink to a shock case

In open warfare these stations were of necessity simple and even rudimentary both as to shelter and equipment.[12] Proximity to the front and a location accessible to litter bearers both forward and rearward were absolute essentials, and frequently on account of the paucity of shelter and evacuation routes the stations of different regiments, even sometimes of those of different adjacent divisions in a narrow sector, consolidated. The distance from the front varied from 50 to 500 yards or more and was often in the support line. Advantage was taken of any possible shelter, such as a shell hole, quarry, culvert, cellar, or dugout, in locating the station. Supplies in addition to individual equipment consisted only of those that the personnel could carry up in gunny sacks and similar containers, and articles such as litters, splints, and

blankets, accompanying the evacuated patient were replaced by the bearers or ambulances by a system of exchange. The service simulated that of trench warfare in so far as possible. Immediate evacuation was the goal, but patients frequently had to be held until nightfall, and there were few or no facilities for treating shock. In attack the medical personnel with the front line usually applied first-aid dressings, and immobilized fractures when possible, leaving the wounded sheltered as far as practicable for collection, a few hours later, by the aid-station bearers, while they continued forward with the line. Similarly, if the movement was rapid the aid station, in moving forward to successive new locations, left the wounded, after administering to them as far as possible, at some centrally located "collecting point" for the facility of the following evacuation ambulance company.[12]

With respect to surgical treatment, the procedures which obtained in the battalion aid stations may be summarized as follows: (1) Revision of the first-aid dressing. Pain, when present, was usually due to constriction of the wounded parts by gauze and bandage, which required changing or loosening. (2) Revision of splinting to insure proper immobilization for subsequent transportation. Application of the Thomas leg or arm splint when traction was indicated.

To arrest severe hemorrhage, whenever the element of time, available surgical facilities, and good surgical judgment permitted, the bleeding artery was sought in the wound and ligated above and below its laceration. If the primary search was unsuccessful and subsequent attempts necessitated material enlargement of the wound, it was often more desirable deliberately to seek and ligate the vessel beyond the wound margin, under conditions of strict surgical asepsis. Prolonged forcipressure—i. e., clamping artery forceps on the bleeding vessel or on the mass of lacerated tissue from which blood was oozing—sometimes succeeded in arresting the hemorrhage. It was possible thus for the forceps, properly padded with dressing, to be left in situ and the patient evacuated to the triage with this fact recorded on his field tag. Whenever, as a last resort, a tourniquet was used and left in situ, this fact was recorded and the ambulance driver or orderly instructed to loosen it for periods of five minutes at intervals of an hour. Only dire necessity justified the evacuation of a patient with tourniquet on arm or thigh. The duration of the journey from the ambulance head to the field hospital was so uncertain, and the prevention of intermittent loosening of the tourniquet because of inevitable traffic blockade, was so likely to occur, that every effort was to be made to ligate or apply forcipressure in all cases in which the rate of blood flow was sufficient to jeopardize the life of the patient. The maintenance of the body heat of the wounded by means of blankets, coats, hot-water bottles, canteens filled with hot water, and hot drinks (when not contraindicated by the nature of the wound) was vastly important. Any chilling of the body precipitates or aggravates shock, therefore every effort was made to have the wounded soldier leave the battalion aid station as thoroughly warmed as battle conditions permitted. Antitetanic serum was administered habitually, even in case of an apparently trivial wound, and the fact of administration recorded

on the field tag, and indicated on the patient's forehead by a cross painted with iodine. If the wound or dressings involved the forehead, the cross was painted on the dorsum of one hand. The standard dose of morphine, one-fourth grain, was given immediately to all severely wounded, and to those slightly wounded in whom the single element of pain was considered to be a factor in the development of shock. Often it was advantageous to repeat the dose: Pain frequently did not become marked until during the transit to the field hospital and a comfortable journey was to be insured by the use of sufficient morphine.

Operative Technique

In battalion aid stations, it was usually impossible for the surgeon to scrub his hands and change gloves for each wound treatment: Water and gloves were not always available, or the supply was very limited. However, instruments could be sterilized sufficiently by immersion in alcohol or ether, and by experience the surgeon could easily learn to dress all wounds without having his hands make contact with septic tissues or objects. With two pairs of dressing forceps, or with one pair each of artery and dressing forceps, he could accomplish any kind of dressing and continue with a series of cases without scrubbing his hands or changing his gloves after the completion of each. He usually had an enlisted assistant, previously trained to apply bandages and splints under his supervision.

THE REGIMENTAL AID STATION

As stated above, when we first entered the war the regimental aid station was the most forward unit aid station prescribed by field service regulations, but with the change of tables of organization increasing battalions to practically the former size of regiments, it was succeeded by the battalion aid station and became almost obsolete, though maintained in a few instances.[12] The term persisted but usually signified merely the station and office of the regimental surgeon and the liaison point of regimental medical service, where service was rendered the regimental headquarters detachment, which was usually at or near regimental headquarters. The function of the regimental aid station when employed, was similar in both trench and open warfare to that of the battalion aid station and it sometimes served, especially in open warfare, as a collecting point for both the walking wounded and those for ambulance evacuation.[12] In the confusion of attack, bearers conveyed the wounded to any point at which a medical officer was known to be, consequently the station of the regimental surgeon frequently became an additional temporary battalion aid station.

THE DRESSING STATION

The number and locations of divisional dressing stations were dependent upon the roads, available shelter and the width and activity of the divisional sector; generally from one to three to a division, located from 3,000 to 6,000 yards from the front line.[12]

In trench warfare the dressing station, usually located in a dugout or in any available building, contained a greater amount and variety of equipment than was possible in open warfare, and had separate rooms for such purposes as

FIG. 85.—Regimental aid station, 321st Infantry, October 3, 1918

FIG. 86.—Dressing station, Croix de Charemont, August 17, 1918

FIG. 87.—Ambulance company dressing station, open warfare

FIG. 88.—Dressing station, Lahayville

receiving, recording, and dressing the wounded, for shock treatment, the serving of hot foods, and for administration. Since more time was available for the care of men brought to the dressing station than was true under open-warfare conditions, many who were merely exhausted were returned to duty after a few hours' rest during which they were given hot food; also, casualties depleted by hemorrhage or suffering from shock could be retained longer and consequently evacuated in better condition. The personnel usually worked in shifts.

In open warfare, buildings or other shelter were not always available and the dressing station was frequently under tentage, which sometimes was but a tent fly. Each dressing station was placed as near the front as conditions permitted; the location selected being generally with a view to its subsequent occupation by a field hospital as the action developed. Occasionally an advance dressing station, with reduced personnel, was established 1,500 to 2,000 yards from the front line, or nearer when possible, as a relay between battalion aid stations and the main dressing station.[12] Commonly, the dressing station sections of two ambulance companies were utilized in the establishment of a main dressing station, one as an advance dressing station and the fourth held in reserve; often three were combined in one station and again each company operated its own station, the tactical situation being the decisive factor. Equipment was limited and in general consisted of dressings, splints, litters, blankets, antigas supplies, antitetanic serum, a few instruments, and drugs, including morphia, and kitchen equipment. The dressing station in a few instances was employed as a triage, in which event the division specialists were stationed here, but this was not habitual.[12] The function of the dressing station in general was to receive casualties, to administer indicated emergency treatment, and to group and evacuate to designated destinations when conditions permitted, but habitually to field hospitals. The emergency treatment comprised arresting hemorrhage, readjusting dressings, applying or readjusting splints, administration of morphia and of antitetanic serum when time permitted, stimulation by hot drinks and the retention and reviving of gassed and shocked cases as far as possible. Operations were limited practically to the closure of aspirating wounds of the chest, and to emergency ligations.

Since casualties usually came or were brought to the dressing station in groups the personnel could not always work in shifts, otherwise the service in general was similar to that of trench warfare. Because all Medical Department activities here were to subserve the prime function of evacuation, professional interference was reduced to the lowest possible minimum. Morphine was administered generally to the severely wounded; great importance was attached to the giving of hot food, for, as mentioned above, many with minor wounds required nothing more and after being fed voluntarily returned to the front line.

THE FIELD HOSPITAL

The field hospital was the last and largest divisional unit of the Medical Department in the chain of evacuation, the function of which in general was to receive casualties from the dressing station, and to institute all measures possible under varying conditions to best fit them for continued evacuation,

FIG. 89.—Unloading severely wounded at Field Hospital No. 28, Varennes Meuse, October 2, 1918

FIG. 90.—Slightly wounded awaiting readjustment of dressings, Field Hospital No. 28, October 2, 1918

usually to evacuation hospitals. Field hospitals were located from three to eight miles from the front line, depending upon such factors as the enemy range of fire, roads, fuel, water, availability of buildings, and the locations of evacuation hospitals.[12] Whenever possible they were grouped, preferably in a village or at the confluence of roads from the sector served, for convenience both in the interchange of patients and for the ambulances.

In trench warfare and in some quiet sectors the field hospital was of a semi-permanent character and was often elaborately installed with modern equipment and conveniences in well adapted commodious buildings or well arranged dugouts.[12] The equipment in addition to all surgical essentials included electric lights, portable radiographic and laboratory units, steam sterilizer, and other similar conveniences. In a few instances they, complete with equipment, were taken over from the French.[12] Usually, under these conditions, one field hospital functioned as triage and cared for the wounded and gassed, one cared for the sick, one for skin and venereal cases, and the fourth was held in reserve frequently conducting a convalescent camp for transportable patients and supplementing the other three as required. All cases likely to become fit for duty in from 10 to 14 days were held. While no definitive measures were undertaken, greater latitude and freedom of action within the discretion of the staff was customary than usually proved possible in open warfare.

In open warfare the situation presented all phases, from conditions obtaining in quiet sectors during periods of quiescence, simulating trench warfare, to the intense activity of attack and advance in which improvisation and individual resourcefulness were the prime factors. When equipment was sparse and of the simplest, often no patients could be held, operations and professional work were reduced to a minimum and the work resolved into a problem of evacuation. On the other hand, in a few instances, as in the cases of the 2d Division at Chateau-Thierry,[13] and the 3d Division at Chierry (August, 1918) and also at Verdelot,[14] conditions obtained whereby the field hospitals were located in commodious buildings with clean, well-lighted operating rooms in which modern aseptic surgical work was done by attached special surgical teams, which included nurses.

The normal personnel of the field hospitals usually was augmented by the division specialists of the various branches and at times also by special operating and shock teams. In a few instances, their facilities for the care of nontransportable wounded were increased by the attaching of mobile surgical units.[12] Also, additional enlisted men were attached, as occasion demanded, who were usually trained for and assigned to special semipermanent team duties.

The equipment necessarily varied with conditions and ranged from that which was complete and even elaborate, including a portable X-ray outfit, which also supplied electric lights in trench warfare and in quiet sectors, to that which was scant and often in part improvised in periods of great activity and rapid movement.

The following description of the surgical work of field hospitals extracted from a report of the 3d Division, in general terms, is fairly typical of that of other divisions, though there were so many differences in details, both in this

division at various times and between this and other divisions, that it is illustrative rather than of universal application:[14]

In operating the hospitals, officers and enlisted men were divided into two shifts, as far as possible, working from 7 a. m. until 7 p. m., although at times all were on duty for longer periods. Division specialists made regular visits to the field hospitals for purposes of consultation and supervision of cases in their own special branches.

The receiving ward of the triage hospital of the 3d Division in the second battle of the Marne was located in an Adrian barrack; the surgical dressing room was in a smaller building at the rear, and the shock and operating rooms were in a smaller building across the street. Near it were the ward tents. When patients were taken from ambulances at the receiving ward, litter cases were carried as far forward as possible, and litters set on the floor on one side of the building, while sitting patients occupied benches along the other side. The record desk at the far side of the building was passed by all patients as they left this room. The receiving officer examined litter cases, sorting out the nontransportable, those to be re-dressed, and those who were to be evacuated immediately. He designated proper wards for all others and designated those who could have liquid or other food. He checked diagnosis tags and especially the records regarding antitetanic serum. Those having no record or proper mark indicating that they had received serum were given the prophylactic dose here. When possible, the record of the case was taken at this time. This first examination was quite thorough, for diagnosis tags were often written under shell fire and frequently failed to record all the wounds the patient had received. When additional wounds were found they were noted on the tag. The tags were also checked to verify nontransportable cases, especially those with active hemorrhage, which were given first consideration. Their records were taken at once, and they were sent to the dressing room or the shock ward. Many shocked cases were warmed in the receiving ward, given morphine, hot liquids, and other foods, and reacted so well that they were transportable. Morphine in large doses from a stock mixture was given in the receiving ward to many cases marked for evacuation, such as patients with joint lesions which were well splinted, fracture cases, etc. Injury to the hands and feet caused more pain in proportion to the amount of tissue destruction than any other classes of cases. Cases for re-dressing, not in a state of shock, were sent to the well-heated dressing ward, where care was exercised to reduce to a minimum the exposure of patients while being dressed and to perform accurate work. Many first-aid packet dressings applied on the field had slipped out of place; but this was seldom the case when two or three pieces of adhesive plaster were used to secure the bandage to the skin. Very few tourniquets were found tight enough to impede circulation. They had generally been loosened at some forward dressing station and bleeding controlled by adequate packing and well-applied bandages. Many of the tourniquets that had not been loosened cut off the venous flow only.

In the rush of work, fracture cases with a good splint that looked comfortable, showed no evidence of shock or hemorrhage, and did not complain of much pain or tight bandages were considered transportable. When but few cases were being received, nearly all fractures were sent to the re-dressing ward for a careful examination. The most common defect in dressings was that bandages were too tight, especially on the forearm, the upper third of the leg, or about the ankle. Many patients complained of pain at the site of fracture or wound, which was relieved when a tight bandage at some distant point on the limb was loosened. Fracture cases were prepared for evacuation by the use of salvaged clothing packed loosely about the limb, and masks were used for pillows. Care was taken in case of fracture of the extremities that the Thomas splint was properly applied and that excessive bleeding was not taking place. When found necessary to hold fracture cases, they were sent to the appropriate ward, kept warm and free from pain. There were very few that required active shock treatment after being prepared and classed as transportable.

Sick patients whose condition was not serious were sent to the medical wards. Usually a separate hospital received these cases. Those with trivial conditions who were able to return to duty within a few days, were retained; the others were evacuated. Transportable surgical cases awaiting evacuation and the slightly wounded who might be returned to duty

in a day or so were sent from the receiving or dressing wards to the surgical wards for slightly wounded, and they also were retained.

Hot drinks, food, and water were available in the receiving wards and were given to practically all cases except those with penetrating wounds of the abdomen. Soup, coffee, and chocolate were the three hot drinks used, and when more than one was available patients usually preferred the first mentioned. Food of all kinds was served, including delicacies furnished by the Red Cross and articles taken from the regular ration. To keep hot liquids or other food, a two-burner kerosene stove was set on a block in the receiving ward, but during rush periods liquid nourishment was served direct from kitchen containers.

On the whole it can be said that the condition of the patients received on the Marne was not as good as those received in the Meuse-Argonne offensive, where we operated close behind the lines. The trip of 17 kms. by ambulance from Château-Thierry to Verdelot was attended by considerable jolting and there was a longer interval between the time of injury and hospital treatment. This was offset by the fact that better hospital facilities were afforded by good buildings, operating rooms, skillful nursing by trained female nurses, and freedom from the dangers of shell fire.

The shock ward received all shock cases, whether the condition was present on admission, developed in other wards, or was subsequent to some surgical operation. All wet clothing was removed from the patient and he was wrapped in warm blankets, arranged on a litter in such a manner as to permit the heat from two primus stoves, or solidified alcohol cans, placed underneath, to circulate within the folds of the blankets and about the body of the patient. The blood pressure and pulse were taken frequently; and, in a case where collapse was threatened, intravenous injections of saline solution or 5 per cent acacia were given until the patient rallied. Some surgeons preferred the gum acacia to the saline solution, but from the small clinical experience obtained in field hospitals it was impossible to derive any conclusions of value. Blood transfusion was resorted to on a number of occasions. The technique of this procedure was fully explained and supervised several times daily by surgical consultants experienced in the method. The donors were classified and were usually obtained from among very slightly gassed patients.

Most of the shock cases were caused by gunshot wounds of the abdomen, head, thigh, or knee, and in many of the last-mentioned wounds the shock seemed out of proportion to the character of the wound. When cases were admitted that required surgical treatment they were first revived by the above method and then sent to the operating room. On the Marne all cases from the operating room were sent to the shock ward for examination, and treatment if necessary, before they were sent to the surgical ward. The shock ward retained the majority of its cases about four hours and had a mortality rate of about 10 per cent.

Re-dressing was done mainly in the surgical ward for slightly wounded. A medical officer was on duty here constantly to apply dressings, to detect developing shock and hemorrhage, and to supervise generally the work of the ward. Feeding was of great importance in this ward. Many face cases required the use of a rubber tube. Morphine and codeine were practically the only drugs used. Hypodermic injections of sterile water were found efficient in many cases. As the use of Dakin's solution exercised a mental effect, it was used in most of the cases and was applied every two hours. In gunshot wounds of the extremities the elevation of the limb afforded great relief in many cases. Active hemorrhage was very infrequent in cases that were re-dressed; usually wnen found it complicated injuries about the hands and face. Tight packing with large shell-wound dressings and properly applied bandages left few cases requiring ligation.

In the operating room most of the work consisted in controlling hemorrhage, removal of foreign bodies, débridement of wounds, adjusting fractures, and otherwise preparing the patients for evacuation. In the Marne battle, after July 15, most of the surgical work was performed by special surgical teams attached to the division for that purpose. From July 15 to 20 three operating teams operated continuously on head, chest, abdominal, and thigh cases, which had been classed as nontransportable. Beginning the first week of August, three teams were in constant operation at Chierry on the Marne, in Field Hospital No. 27, on this same class of patients. They rendered great service to the severely wounded, and brought to within a short distance from the firing line the skill of experienced surgeons and

nurses. Both at Chierry and at Verdelot the surgical operating rooms were located in excellent buildings, with good light and clean surroundings, making thoroughly aseptic work possible. Before and after operations the shock teams with their surgeons and nurses, worked over many apparently hopelessly wounded men. The radiographic unit, operating in close proximity to the surgical room, proved invaluable. But few plates were made, as the fluoroscopic method, being rapid and accurate, was used almost exclusively. After fractures were reduced the work was checked up under the fluoroscope.

The following discussion of the surgical service in the field hospitals of the 42d Division is also quoted,[15] for it illustrates in many respects the methods employed and the conclusions reached. The methods differ in some respects from those of the 3d Division, which are quoted above. The descriptions of the work of these two divisions are the most explicit that can be found:

It was the universal policy to evacuate at once to the rear all cases capable of bearing the trip, so that operative surgery in the field hospital resolved itself into treatment of the seriously wounded; that is, of those whose condition was such that further transportation was both inadvisable and dangerous to life. Very early in the campaign it was realized that for the most part field hospitals must rely on their own resources in the care of such cases, for in an active fighting unit, moving rapidly from one sector to another, it was impossible to depend upon the arrival of specially trained operating teams from the rear. The hospitals had to be as mobile as the division and able at a moment's notice to care for the wounded. In spite of surroundings and regardless of whether units were working in well-equipped hospitals or in barns or tents, provision always had to be made for prompt action in those cases requiring immediate surgical intervention. At an early date, in order to be prepared for any contingency, six operating teams and four shock teams were organized from the personnel of the section. Operating room assistants, anesthetists, orderlies, and litter bearers were selected and given special training. Operating and shock teams worked in relays, thus allowing periods for rest. The mobile X-ray equipment was a valuable adjunct to operative work, making possible the location of foreign bodies and the demonstration of the extent and nature of fractures. On several occasions it furnished light for the operating room. At times the drain on sterile dressing was so great that it was necessary for hospitals to do their own sterilizing. This was accomplished by a fairly large portable sterilizer of French design, which served the purpose admirably. Operating routine was essentially the same in all cases.

On arrival at the field hospital cases were sorted and classified according to the nature of the wounds and also with regard to the condition for further transportation. Cases presenting symptoms of shock were taken at once to the shock room for special and immediate treatment.

In the preoperative ward patients were again closely examined with a view to determining which needed prompt attention. All such were picked up on the following special chart:

PREOPERATIVE WARD

Name------------------------------ Date and hour received------------------------

Condition:
- Good.
- Fair.
- Shock—
  - Traumatic.
  - Hemorrhagic.

Nature of injuries:

Physical examination:
- Conscious.
- Unconscious.
- Semiconscious.

Chest wound:
- Open.
- Closed.
- Hemo- or pneumothorax.

Urine:
- Amount.
- Blood or clots.

Vomiting:
- Frequency.
- Amount.
- Character.

Hematoma:
- Location.
- Pulsating.
- Bruit.

Tourniquet:

Paralysis:
- Location.
- Sensory.
- Motor.

Abdominal wound:
- Location.
- Physical symptoms.

Stools:
- Normal.
- Blood.

Fractures:
- Location and description.

Disposition:
- X-ray.
- Shock ward.
- Operating room.
- Died.

(Signed) --

This chart was found to be invaluable from many standpoints, especially from the fact that it necessitated careful examination of all patients. Crowded and insufficiently lighted advance aid stations, rapid evacuation from these stations under shell fire, and divided responsibility at times resulted in failure to record the use of tourniquets or the detection of hemorrhage. In the same connection, one case of morphine poisoning was observed, but, fortunately, was discovered in time to prevent a fatality. * * * The case is cited to show the danger of failure to record the use of morphine, for as the patient was badly shocked as well as poisoned, it would have been pardonable for the entire syndrome to have been attributed to shock alone.

Of equal importance was the advisability of recording all obtainable data concerning the nature of the wounding agent as well as the manner in which the wound was sustained. It was a well-recognized fact that shell fragments or bullets entering the body might travel in any direction, leaving no external clue to their subsequent course, the final destination of a missile being determined by its nature, velocity, and angle of entrance. Given a chest wound, a bloody vomitus would be strong evidence that the missile had passed through the diaphragm and penetrated the stomach, and to omit this evidence from the records was a serious mistake, for, although a perfect operation might be performed on the chest wound, the complicating abdominal injury untreated would surely have been fatal. On the other hand, when a patient came to the operating room a carefully taken description of his wound saved valuable time for the surgeon and for the patients who were painfully, though patiently, waiting their turn.

Every shock case upon reaching a field hospital was sent at once to the shock ward and the patient's record kept on the following report chart:

SHOCK WARD

Name:
Nature of injury:
Blood pressure:

Individual report.
Organization.
Date and time of injury:
Date and time received:
Condition of patient:
    Moderate or severe shock.

Treatment:
    Infusion, c. c.
    Transfusion, c. c.
    External heat.
    Morphine.
    Stimulants.
    Specify any other.

Tourniquet:
    Location:
    Duration:---------- hours.

Effect of treatment:
    Improved:
    Unimproved:
    No response:

Disposition:
    Time.
    Operating room.
    Evacuated.
    Died.
Was patient returned from operating room, and final disposition?

This chart was adopted in order to permit a close study of the cases treated for the purpose of determining the relative value of the various forms of treatment. Upon arrival of a case in the shock ward the litter was placed on a pair of low trestles, one for each end. The officer in charge made a hurried examination for open or concealed hemorrhage. If none was found the patient was covered with warm blankets and heat applied beneath the litter. Solid alcohol was used for heating purposes, usually four cans to a single patient, these being protected by metal boxes open at one end only. Blankets were then dropped over the sides of the litter to the ground. Warm drinks were given in small quantities if the patient had no abdominal wound or was not slated for early operation. The only cardiac stimulants used were caffeine citrate and camphorated oil, used subcutaneously. Morphine was given, both for the relief of pain and for its general beneficial effect. Gum acacia salt solution was used extensively, with unsatisfactory results, and blood transfusion was not always feasible.

The length of a patient's stay in the shock ward depended upon his condition. If reaction was prompt and there was no special need of an immediate operation he was evacuated. If operation was indicated it was performed as quickly as circumstances would permit.

Anesthetics used were ether and ethyl chloride, preferably the latter, owing to the fact that it induced rapid anesthesia and was well borne. No untoward effects of any kind were observed from its administration. At the close of an operation the patient was returned to the shock ward for further treatment until full reaction had occurred.

A study of shock cases treated by the field-hospital section of the 42d Division led to the following conclusions concerning the etiology of shock: During the early days of the division's participation in active campaign, when the weather was warm and the men were in splendid condition both physically and mentally, the number of shock cases was relatively small. It was observed during this period that even cases in severe shock responded readily to treatment. * * * In striking contrast was the clinical picture presented by the wounded during the closing weeks of the war. Not only was there a greater number of shock cases, running up to 17 to 20 per cent of the severely wounded, but they were far

graver in character, reacting very slowly to the most energetic treatment. Worn out by long fighting, with little chance for rest, exposed to cold, with insufficient protection, constantly wet and insufficiently fed, with cold food—a condition necessitated by the risk which fires close to the line would have entailed—the troops were at a low-water mark of fitness, mentally and physically. * * * The mortality in shock cases was, consequently, extremely high in spite of every possible form of treatment, and the experience of all was that, no matter what the type of treatment, results were most unsatisfactory and discouraging, for the patients were not only wounded but exhausted. This experience coincided with that of other divisions.

It was found that war surgery, like all traumatic surgery, constantly presented three great problems, viz, shock, hemorrhage, and infection. Shock has already been discussed, but it must be emphasized that this was materially lessened by the careful attention given the wounded at regimental and advance aid stations and by the rapid evacuation by ambulance companies of all wounded to the field hospitals. Hemorrhage was controlled by the tourniquet or by direct ligature, which insured the delivery of patients to their destination without serious loss of blood. With regard to infection, it was noted in the early days of the war that the number of wounded men dying from tetanus was very large. Accordingly, a thorough system of immunization was carried out and every wound, no matter how trivial, was considered justifiable cause for the administration of antitetanic serum. So religiously was this plan followed that a wounded soldier rarely appeared at a field hospital without first having received his prophylactic dose of serum. Experience with infection caused by gas-forming bacilli was limited in the field hospitals, owing to the fact that in most instances cases were received promptly after injury and were evacuated before the development of this grave condition. This was true also of the pyogenic wound infections, but an effort was made to prevent all infection by the adoption of well-recognized preventive measures.

In the 42d Division operations in field hospitals were limited to the following classes of cases: Thoracic aspirating wounds, abdomical cases where hemorrhage might be rapidly fatal or a peritonitis imminent, cases requiring amputation, joint injuries, and all hemorrhagic cases.

It was not intended that definitive surgery should be performed in field hospitals except upon certain nontransportable patients, as evacuation hospitals were provided for this purpose. The scope of professional activities in field hospitals varied greatly according to the intensity of the action, but during an offensive it was customary to evacuate all patients as soon as they could endure transportation. After the formation of the First Army its orders required that operations in field hospitals be reduced to a minimum, and similar orders were published in several corps.

Though evacuation hospitals habitually were located well up toward field hospitals, an exception occurred when the 1st and 2d Divisions attacked toward Soissons. During this attack evacuation hospitals were not moved up because no advance information had been given the medical authorities concerned.[16] Also they were at considerable distances from much of the front in the later stages of the Meuse-Argonne operation, on account of lack of railroads in the immediate rear of the divisions.

Because of the accessibility of evacuation hospitals during the first part of the Meuse-Argonne operation, only two types of patients were operated upon in field hospitals, in the 5th Division, viz, those with aspirating chest wounds and hemorrhage.[17] Later, on account of the considerable length of time elasping from receipt of wounds until arrival at hospital, all types of cases were operated upon if they could not be transported to the evacuation hospital within 15 hours after being wounded, except that patients with aspirating

chest wounds and uncontrollable hemorrhage continued to be operated upon irrespective of this time limit. In the 5th Division, wounds operated upon under these circumstances were, relatively, as follows:[17] Abdomen, 20 per cent; chest, 27 per cent; head, face, and neck, 9 per cent; upper extremities, 18 per cent; lower extremities, 26 per cent. No patients were operated upon who could possibly have been transported within the time limit—15 hours—except those whose wounds were so severe that operation was imperative.[17]

The operations performed most frequently in the 5th Division were transfusions and arrest of hemorrhage. In about 19 per cent of the patients admitted to triage, antitetanic serum had to be administered, there being no record of its having been given farther forward.[17]

The following records pertaining to the 32d Division, A. E. F., indicate the plans which were promulgated in that division for the care of its wounded, more particularly in the field hospitals, and in addition show with what success they were carried out under battle conditions:

[Memorandum]

HEADQUARTERS, 32D DIVISION,
OFFICE OF DIVISION SURGEON,
August 31, 1918.

To All Medical Officers, this Division:

INSTRUCTIONS FOR OPERATION OF TRIAGE, THIRTY-SECOND DIVISION

It is essential that all casualties from the front pass through the triage.

The following plan of operation, with minor modifications, has been successfully followed by a field hospital of this division. No radical departure therefrom will be made, except by order of the division surgeon:

1. *Functions.*—The function of a triage is, in general: First, the grouping of casualties as to degree, which determines whether they are (*a*) transportable; (*b*) nontransportable. Second, their classification as to type of casualty, i. e., (*a*) G. S. W.-S, (*b*) G. S. W.-O, (*c*) psychoneurosis, (*d*) gassed, (*e*) injured, (*f*) sick. Other functions of a triage are: 1. The rendering of minor surgical aid and medical treatment in emergencies, to make transportable, if possible, cases that would otherwise be nontransportable. 2. The readjustment, or renewal of dressings and of splints where necessary. 3. The administration of antitetanic serum for immunizing purposes where it has not already been administered. (Accept no evidence that it has been administered other than a statement to that effect on the diagnosis tag or the presence of the characteristic sign on the patient's forehead. A statement by the patient that he has had a hypodermic injection must not be accepted as proof.) 4. The preparation of hot drinks and food, to be given when indicated. 5. The triage is not a collecting station, but a means of separating and evacuating with all possible speed, through proper channels to designated hospitals.

2. *Operations, Records and Reports.*—I. A medical officer shall examine each case as admitted, marking the disposition of case on the back of the diagnosis tag with colored pencil. A clerk will then follow to collect the necessary data; the completion of which he will indicate on tag by a fixed symbol or otherwise. (Cross in circle is suggested.) The noncommissioned officer in charge of litter detail will assure himself that each tag bears this symbol before evacuating such case from triage. II. Accurate and complete record of all patients will be made, listing casualties separately by, first, 32d Division; second, other United States units; third, allied troops; fourth, enemy. And giving in each instance name and Army serial number, rank, company and organization, nature of casualty, disposition. This information will be recorded on Form 4, A. G. O. S. D., A. E. F.; two copies to be forwarded to the division surgeon's office by courier. The period of record thus compiled will be six

hours, 6 a. m. to 12 noon, 12 noon to 6 p. m., etc. III. The nontransportable wounded will be admitted to advanced operative field hospital immediately and directly from the triage receiving tent. IV. A daily summary for the 24-hour period ending 6 a. m. and known as triage report will be prepared and sent by courier to the division surgeon's office as soon after the closing of the period as possible. V. Only cases admitted to field hospitals will be carded on field medical card and reported on Form 22, A. G. O. S. D., A. E. F. Cases dying in triage or enroute to triage will be forwarded and admitted to a hospital, where the necessary records will be made and proper provision made for burial.

3. *Personnel.*—I. The personnel shall consist of two teams; each on a 12-hour tour of duty and composed of (as a minimum) 1 medical officer, 1 noncommissioned officer, 2 clerks, 1 stenographer, 12 litter bearers, 2 men for kitchen detail, 1 ward attendant for each tent in which patients are held, and 2 men for dispensary and dressing room.

4. *Equipment.*—The following equipment has been found adequate: I. One ward tent or other shelter as a receiving ward, with a capacity for at least 12 litter and 40 sitting cases. When feasible it should be well lighted. II. A second ward tent or other shelter for the temporary care and segregation of the seriously wounded transportables while awaiting evacuation. III. A third ward tent or shelter for the temporary care and segregation of slightly wounded sitting cases. IV. A fourth shelter for those cases classified as sick or as psychoneurotic; which are ordinarily sent to one of the division field hospitals. V. A small cover, such as is afforded by a 14 by 14 tent fly, for (*a*) storage of litters, necessary medical supplies, blankets, etc.; (*b*) office. VI. Equipment necessary for the preparation and serving of food.

Enlisted personnel must be especially trained in their respective duties and instructed as to the function and purpose of a triage, namely, grouping of casualties, correct record, speedy evacuation.

G. E. Seaman,
Lieutenant Colonel, Medical Corps,
Division Surgeon.

Headquarters 32d Division,
September 3, 1918.

From: J. W. Vaughan, major, Medical Corps, United States Army.
To: The Chief Surgeon, A. E. F.
Subject: Surgical care of the wounded from the 32d Division during the drive from August 27 to September 2, 1918.

1. Since the report last made upon the surgical care of wounded from the 32d Division several changes have been made in the organization. These changes have been instituted as a result of the experience gained in the Fismes drive, and it is the opinion of those who have had to do the work that they have facilitated in the proper handling of the wounded.

2. The chief change was one put into effect by the commanding officer of Field Hospital No. 127. This consisted in the placing of a triage, in compliance with an order of the division surgeon, a short distance in advance of the operating hospital for seriously wounded, thus separating it entirely from our advanced operative hospital, to which it was attached in our former drive. All wounded were brought to this triage by the division ambulances. These ambulances were unloaded and immediately returned to the front stations for more wounded. In that way no serious blocking ever occurred at the advanced dressing stations.

3. At the triage the patients were sorted out as to the degree of severity of their wounds. Accurate records were also kept of the wounded so that a report of the number, rank, organization, and severity of the wounds could be made every six hours. (It is imperative that the best and most decisive medical men available should direct this work.) The severely wounded were sent to our advanced operative station, which was 12 kms. behind the front line at the beginning of operations. Inasmuch as the distance between the two stations was only about 200 yards, the mule-drawn ambulances were used for this purpose. The less seriously wounded were evacuated by truck and attached motor ambulance company to Evacuation Hospital No. 5, which was stationed 19 kms. farther in the rear. From here evacuation was carried out by train to Paris.

4. One train of wounded was also evacuated by train direct from La Vache Noire to Paris, the latter place being just about 1 km. from the triage, at a time when sufficient motor transportation to Evacuation Hospital No. 5 was not obtainable.

5. The placing of the triage entirely separate from and slightly in advance of the operating station for seriously wounded enabled the officer in charge of the same to send only non-transportable cases to that station. Abdomens, sucking chests, serious heads, cases in shock or apparently standing transportation poorly, and those showing evidence of hemorrhage were the only ones sent.

6. The total number of wounded was 1,758 up to the time of writing this report. Of these, 256 were sent to the hospital for seriously wounded. Of these 256, 41 were so seriously wounded that they died within a few hours after admittance. Blood transfusion, intravenous injections of gum, and other methods used to combat shock failed to be of benefit in these cases. In addition, seven deaths were charged to the hospital, the deaths occurring en route to the triage, the bodies being brought so that our burial squad could attend to them.

7. Operative treatment was given to the 215 cases remaining. Amongst these cases there were 34 deaths. The separate wounds encountered in the 215 cases were 419 in number, and were divided as shown in the following table. The wounds encountered in the cases that proved fatal are also tabulated.

	Wounds in 215 cases	Wounds in 34 deaths
Soft parts	170	17
Soft parts associated with injury of large vessels	7	1
Fractures:		
Femur	14	6
Humerus	15	1
Radius, ulna, tibia, or fibula	37	9
Other bones	46	1
Knee joints	5	
Elbow joints	5	1
Combined chests and abdomens	6	1
Chests (sucking)	41	5
Abdomens, with injury to hollow viscus	25	10
Abdomens, without injury to hollow viscus	11	2
Head and brain	15	2
Amputations	8	1
Cord injuries:		
Partial	3	2
Complete	1	
Symptoms present, but no injury to cord found	4	
Collapsed eyes	5	
Total	419	

Cases showing evidence of fulminating gas gangrene totaled 8; of these, 2 died. Figures were furnished by the adjutant of Evacuation Hospital No. 5 upon September 1, which showed that up to that time 1,635 casualties from the 32d Division had passed through their hands. Of these, 367 were gas cases and 122 medical, leaving 1,146 surgical cases.

8. Of the latter, 676 were operated upon at No. 5, and amongst these there had been but 6 deaths, which showed that the sorting at the triage had been exceedingly well done These showed wounds of chest, abdomen, right and left femur, gas gangrene of right and left feet, and a case of hemorrhage from a neck wound. These cases had been sent on from the triage at a time when the advanced hospital was filled and it was thought that they might receive attention sooner if sent on. This probably should not have been done and was an error in judgment on my part, as possibly some would have been saved if attended to at the advanced station.

9. A good proportion of the cases which so far have survived operation at the advanced institution were in shock, or showed evidence of having suffered from considerable hemorrhage, upon arrival. In fact, the percentage of these cases was so large that a rule was adopted that every case entering the hospital should first be seen by the head of the shock team, and that the order in which surgical attention was given was under the direction of the shock team entirely, inasmuch as through their constant observation they were able

to estimate when a case should be operated upon much better than could the operating surgeon who was busy with many other things.

10. The shock team furnished was No. 116, and their work was of inestimable value. I would request that in the future two teams be assigned to this division, when in an active sector, so that it will be possible for one to relieve the other. It was found necessary to divide the last team and add one more officer from our own divisional personnel in order that this team could functionate in 12-hour shifts.

11. I would again request that two X-ray teams be furnished our advanced operating hospital, so that it will be possible to work 12-hour shifts there also. The team attached to us worked constantly without rest for over 48 hours and carried on with but little sleep for the full six days.

12. One operative team was furnished us by the surgical department for our advanced unit. This was Navy Operating Team No. 1. The work done by this team was excellent, and I would again suggest the necessity of more equipped teams for advanced hospitals during active times.

13. As in our former drive, it was found necessary to make up teams from the officers and enlisted personnel of the division. These were practically the same as those detailed in the report upon activities in the Fismes sector. Six such teams were used, and without such resources it would have been impossible to give the seriously wounded the attention required.

14. An attempt was made to follow up the cases operated upon in our advanced institution in order to ascertain what the ultimate outcome was. A total of 88 cases were seen in the base hospitals in Paris. Of these, 14 had been operated upon at Field Hospital No. 127, and amongst these there had been one death from gas gangrene.

15. Some system of follow-up should be devised whereby a record of these cases can be kept and thus the ultimate value of advanced operative institutions for seriously wounded can be ascertained. It would appear, however, that there is a decided place for small mobile advanced institutions, which should be attached to each division, especially if our evacuation hospitals are to be stationed so far in the rear. Such institutions are absolutely essential in case of an advance of 10 kms. or more if our seriously wounded are to receive proper attention.

(Signed) J. W. Vaughan,
Major, Medical Corps, United States Army,
Consulting Surgeon.

THE EVACUATION HOSPITAL

In both trench and open warfare the evacuation hospital is usually the first surgical formation reached by the wounded that is completely equipped and prepared for the treatment of all cases. At the evacuation hospital, which operated either alone or in conjunction with one or more mobile hospitals, primary operations were performed, emergency operations performed at the more forward stations were revised, the severely wounded were hospitalized until they either succumbed or became transportable to the base, and all transportable wounded, after receiving appropriate treatment, were evacuated immediately in order to make room for other convoys of wounded.

FUNCTIONS

Evacuation hospitals which reached the zone of the armies were operated directly under the jurisdiction of the army surgeon and not under the chief surgeon of the line of communications, as our regulations had stipulated previous to our entry into the war.[18] The army surgeon, cooperating with the

deputy of the chief surgeon, A. E. F., at G. H. Q., supervised their distribution, location, and expansion, coordinated their activities with the service of the front, and, through a medical officer assigned to the regulating station, effected their clearing by hospital trains. In the few instances, when evacuation hospitals were not located on a railway line, the army surgeon effected their evacuation to a railway by ambulance companies under his command.[18] These evacuation hospitals, too, were supplemented by mobile hospitals, which performed similar functions but were smaller and more mobile.

While in certain respects our field hospital continued to be an emergency hospital for the battlefield, it became more nearly a magnified and improved dressing station than a hospital. This made the evacuation hospital the actual theater of our surgical effort there, especially during very active periods. The evacuation hospital, plus the mobile hospital and the mobile surgical unit, thus constituted the hospital for early surgery; upon it, to a very great extent, the patient's life and limb depended. It proved necessary to apply in this hospital with great rapidity, to the most urgent cases, the best treatment known to modern surgery, in order to secure satisfactory professional results, and at the same time, in order to secure the best administrative service, it was likewise necessary to evacuate its patients as quickly as possible to provide beds for incoming wounded. To a certain degree these needs conflicted, and it was only by the utmost diligence and perspicacity that they could be reconciled in periods of stress, or, that, if this proved impossible, their conflict could be reduced to a minimum.[19]

FIG. 91.—Sorting wounded

It should be explained here that our medical service did not accept the tenet of our Allies that the more lightly wounded should receive preferential attention in the zone of the armies because of the greater probability of their return to active service, and also because a greater number could thus be cared for in a given period.[20] Increased knowledge of surgery proved that removal of devitalized tissue and foreign bodies from slight wounds could be accomplished successfully back of the zone of the armies, and that surgical interven-

tion within 12 hours was not essential in the slighter cases in order to prevent infection by the gas-forming bacilli.[21] The earlier belief that early operation was essential in all cases had an important influence, however, in causing the British and the French to locate so many large, relatively immobile hospitals so close to the front. Their entire evacuation hospital service was also profoundly influenced by the fact that shell wounds, so common in this war, were practically always infected by gas-forming organisms, and that, in order to get the best results, operation was advisable within 12 hours after injury.[21] At such operations foreign bodies were removed, the wound débrided and left open until bacteriological examination showed that its closure was warrantable. This last procedure, in uncomplicated flesh wounds, was usually possible in four to five days and recovery was complete in from three to five weeks. No one questions the necessity for very prompt action in serious wounds, but it

FIG. 92.—Wounded awaiting admission to hospital

had also been believed that return to the colors would be expedited if the slightly wounded as well as the seriously wounded could be operated on within 12-hour limit of time. Later observations showed that practically the same results were obtained in the slightly wounded, without retained foreign bodies, if operation were delayed 24 hours or even longer. Upon this knowledge was based the American policy of sending such cases farther to the rear for operation if pressure was such that their numbers would overtax an evacuation hospital of approximately 1,000-bed capacity at the front.[21]

Our evacuation hospitals then sought especially to give surgical treatment to severely wounded patients whom it was not advisable to send, unoperated upon, farther to the rear, and then to hospitalize such patients until they were fit to be moved, so far as might be necessary, but only, as circumstances permitted, to hospitalize here also the less seriously injured. As a rule, the treatment given the latter was temporary, though sometimes it was definitive, but

this was only if the demand for beds was not pressing. In times of great stress there were never enough evacuation hospitals at the front to give full surgical attention to all the wounded; nor was it proposed that there should be, for such provision would have required an excessively large hospitalization in the zone of the armies. Except for the small percentage of very seriously wounded who had to be hospitalized in evacuation hospitals because they could not endure transportation to the rear, our evacuation hospitals were merely relay or clearing stations in the hospitalization and evacuation chain.

While the more seriously wounded properly required two weeks' hospitalization after operating before being transferred, sometimes the demand for beds was so great that the more seriously wounded had to be removed in less than half the time. Brain injuries, if operated upon here, were kept, if possible, at least 10 days. Knee-joint, abdominal, and chest wounds were retained from 10 days to two weeks when possible, but patients with these wounds sometimes were evacuated after five days, or, very rarely, in even less time. Patients

FIG. 93.—Admission office of an evacuation hospital

with compound fractures of the femur were kept as long as possible.[21] It was estimated that about 10 per cent of the beds in evacuation hospitals would ordinarily be used for the severely wounded and the remainder for patients to be evacuated immediately. It was recognized, however, that this proportion, like many others pertaining to evacuation hospitals, was subject to radical modification in order to meet the constantly shifting military situation and its hospital requirements.[21] Elasticity of this hospital proved essential in both size and service.[16]

The capacity and organization of individual evacuation hospitals were based, to a certain extent, on an estimate of what the maximum daily admissions would be. With some exceptions these did not exceed 1,000, but on some occasions there were more than 1,400; for example, in Evacuation Hospital No. 9, on October 10, 1918, during the Meuse-Argonne operation.[22] Excessive pressure, due to the intake of more patients than an evacuation hospital could care for, was controlled by sending patients out on "preoperative trains," though

some hospitals objected to this practice on the ground that it indicated inability of the institution to handle patients properly. It was contended also that the time which must elapse before these patients could be delivered by train to hospitals in the rear would exceed the length of time they would have to await operation in the evacuation hospital concerned and that their chances of infection would thereby be increased. In any event, these patients were transferred from the evacuation hospital only after very careful examination and re-dressing. The transferable were held to include those with such injuries as fractures caused by rifle and machine-gun bullets, but without much bony destruction; gutter wounds; and flesh wounds with retained bullets. But local demands and the resources available at the time really determined what classes of patients should be transferred. An important factor influencing the use of preoperative trains was the number and rapidity of operating teams available at the evacuation hospitals. The number of operating teams was increased in the evacuation hospitals; then work was speeded up. The number of unoperated patients it was necessary to evacuate from the evacuation hospitals during the Meuse-Argonne operation fell from above 1,370 in the first phase of that engagement to 293 in the second.[23]

When the 24-hour intake of patients at an evacuation hospital exceeded 1,000 the routine plan of work ordinarily had to be changed if all patients were to be cared for locally. The necessary speeding up of operating teams under such circumstances depended on their good organization. Shifts at the eleventh hour generally proved unsatisfactory, and it was found that sometimes, due essentially to inadequacy in number, experience, and speed of operation teams, preoperative trains had to be used. How severe the pressure was at times is indicated by the fact that in the six weeks subsequent to June 13, 1918, Evacuation Hospital No. 7, at Coulommiers, near Château-Thierry, received and evacuated 27,000 cases. Between June 14 and November 11, 1918, it admitted more than 50,000 patients,[24] while Evacuation Hospital No. 9 admitted more than 32,000 during the Meuse-Argonne operation, September 26 to November 11, 1918.[22]

Generally speaking, more than half the patients admitted to evacuation hospitals in the zone of the armies were surgical cases, and of these about half were operated upon. Data on this subject, however, are incomplete, and these figures apply only to those hospitals which reported on this subject.

The quota of personnel on duty in the receiving ward also differed somewhat in the several hospitals, but usually it consisted of 2 officers, 1 sergeant, 8 clerks, 2 guards, and 8 or 10 litter bearers. Officers on duty here gave emergency treatment in case of hemorrhage, supervised litter bearers' activities, the preparation of records, and the care of valuables, made appropriate note on the admission card of a patient if antitetanic serum had not been administered and distributed patients to wards for gassed and medical patients, to the dressing tent for walking wounded, to the preoperative ward or to the shock ward, as the case might be. Records were made here giving each patient's name, his military designation, diagnosis, and any other necessary data obtained from personal interrogation and from an examination of his field card and diagnosis tag.[20] If the patient was unconscious these facts were obtained

from other patients accompanying him and from his identification tag, as well as from the other sources mentioned.[25] In some hospitals a nominal list was usually made on the admission of patients, and two copies of Form 52 were made out for each patient in the wards. One of these was sent to the sick and wounded office at once, and this furnished the data for reports called for from the hospital. The other copy was turned into the sick and wounded office when the patient was evacuated. In other units complete records were made, so far as this was possible, in the receiving ward, and these records were supplemented later by data from the operating room and wards. Walking wounded who were seriously injured were sent to the preoperative ward, tagged for immediate attention. Similar tags were placed on shock patients and on those with tourniquets.

The dressing room for the slightly wounded was located near the receiving tent. Its equipment was simple, consisting of one or two operating tables, benches, a table for instruments, and dressings and utensils which had been sterilized in the main sterilizing room.[25] One or sometimes two officers, assisted by one or two nurses and by two or three enlisted men, were on duty here. At this point a second sorting was effected. The officer on duty examined, dressed, and recorded patients admitted to this department, giving antitetanic serum to such patients as had not already received it. Patients requiring immediate operation or who might be evacuated at once (on litters, if the pressure was great) were properly tagged and sent to the preoperative ward. Patients whose conditions were not critical, requiring X-ray examination, were sent to the X-ray department. Since patients with very serious injuries—for example, injuries of the large blood vessels and even compound fractures of the skull—were sometimes ambulatory, careful attention was given every wound, however slight it might appear to be. At this point, too, careful search was made for injuries of nerves and blood vessels. Provisional diagnosis and administration of antitetanic serum or morphine were noted on the patient's field medical card.[25]

Other patients than those already mentioned were sent to the wards for slightly wounded, or to the evacuation ward, after their wounds had been dressed and they had received hot food or drinks if, as in some hospitals, these had not already been given in the receiving ward. Slightly wounded patients who had developed intercurrent diseases, such as pneumonia, dysentery, or the like, were sent habitually to the appropriate medical wards.[25]

Decision as to whether slight wounds should be operated upon was based on the rate of admissions, the number of surgical teams and their speed. It was found that an experienced team operating two tables often handled 35 or 40 minor patients during its shift; later this number was notably increased because of better organization and improved skill, until many teams operated upon more than 60, some more than 80 patients, and one team more than 90 patients, during the daily shift.[23] In periods of comparative quiet at first practically all surgical patients admitted were operated on, and toward the end of the war this was the case even during periods of great military activity. The chief of the surgical service kept his teams fully occupied, the number of preoperative patients transferred being limited only by the surgical facilities locally available.[25]

The third major sorting of patients was effected in the preoperative or classification wards, which received the wounded admitted on litters and certain ambulatory patients sent from the dressing tent. Patients received here required 80 per cent of the professional skill available in an evacuation hospital. At this point, on alternating day and night shifts, were stationed the most experienced men on the professional staff, selected with regard to accuracy and rapidity of decision and adjustability to the constantly shifting standards which controlled the disposition of patients. The quota of nurses and orderlies in this department was large; usually there were 1 officer, 1 nurse, and 4 enlisted men to each ward. Day and night shifts were provided. Patients were undressed, bathed, if possible, and their wounds were examined and dressed. When possible they were undressed in one tent and their wounds were dressed in another.[20]

In some hospitals a sketch and description of the wound were made when patients were being bathed, and this record accompanied the patient to the operating room. If the patient's condition was critical, his clothing was not removed until he had been anesthetized, or, if he was badly shocked, not until rising blood pressure warranted it.[20]

In the preoperative ward waiting patients received morphine, if this was needed, and hot drinks and food if these had not already been administered or if desired.[25]

The success of an evacuation hospital's service was commensurate in very large degree to its methodical and successive distributions of patients. At the three points mentioned above—receiving ward, dressing room, and preoperative ward—it was essential that there be prompt, accurate diagnosis and immediate distribution in conformity with very changeable demands for evacuations. Distribution from the preoperative ward was determined primarily by the number of patients to be cared for and by the facilities for operating, and not entirely by the patient's condition. When operating teams were limited in number, or were inexperienced, a rapid influx of patients would change the standard of selection of patients for operation from all-litter and the more serious walking cases into, for example, a very much more restricted class composed chiefly of patients with abdominal wounds, aspirating chest wounds, and fractures of the femur by shell fragments. Under such circumstances patients had to be sent out on preoperative trains until operating teams were furnished in sufficient number and had acquired sufficient speed to care for them.[20]

Only in exceptional cases were patients sent from the preoperative ward direct to the operating room. These included patients with active hemorrhage, or patients received with tourniquets in place, and with certain fractures without splinting.[20]

The preoperative ward, X-ray section, operating rooms, and wards for the severely wounded were grouped as near together as possible, for it was essential to reduce carriage by litter to a minimum. If this was not done, it was found that litter squads were exhausted after a week's offensive.[20]

Patients were distributed from the preoperative ward, according to rate of admission and available operating facilities, into (*a*) special wards for head,

chest, and abdominal patients; (*b*) shock ward; (*c*) X-ray ward; (*d*) operating rooms; and (*e*) evacuation ward.[20]

In some hospitals, to facilitate their care, patients with head, chest, or abdominal wounds were segregated in a special ward which accommodated both preoperative and postoperative patients. Such a ward was best located next the shock wards, but was not attended by the same personnel, the shock teams being fully occupied in their own department. When this arrangement was followed, this special ward received, among others, patients who were too badly shocked to undergo immediate operation.[20]

The special ward for head, chest, and abdominal patients, containing those both operated and unoperated upon, was in charge of one of the most competent

FIG. 94.—Recovery ward of an evacuation hospital

officers available. If patients with head injuries were to be operated upon before evacuation, the operation was performed as soon as possible. Patients with abdominal wounds were operated upon as soon as their condition warranted. In injuries of the chest immediate operation was indicated in only a small group of cases: (1) Aspirating chest wounds; (2) large retained foreign bodies; (3) severe injury of bones; (4) complicated lesions of the diaphragm.[20] Other chest wounds were sent to this ward for observation and were there placed in the sitting position, given morphine, splinted by adhesive plaster when this was called for, and administered other necessary treatment. A combined infection by *B. welchii* and streptococcus usually required operation, but a large majority of the chest wounds did not require surgical intervention.

Those requiring it were X-rayed, and in many cases it was found that if the missile had originally been embedded in the lungs it had dropped down and could be removed from the bottom of the chest cavity. A thorough examination of the wound was made and drainage established if needed. Preoperative treatment of head, chest, and abdominal wounds, and decision concerning operation, required special care, skill, and judgment. Head wounds, no matter how severe, usually did better if treated at once, but such interference delayed the evacuation of the patients concerned by some two weeks. Whether operations should be performed here or deferred until the patient reached a base hospital where he could remain indefinitely was a highly controversial subject.[20] From a professional standpoint, operation on head wounds at an evacuation

FIG. 95.—Heating chamber for shock cases

hospital was indicated; from a military standpoint —that is, the necessity for evacuation —it usually was not. This was one of the instances where individual and general interest conflicted.[20]

For the shock ward a Bessonneau tent usually was employed, equipped with all means for treating shock, including heat, posture, morphine, fluids, and gum acacia solution, or citrated blood. It was adjacent to the preoperative ward, and in addition to being kept at a high temperature—90° F.— was equipped with hooded tables which further secured warmth to patients in a state of shock. In general, this ward received patients with blood pressure below 100, and other patients as condition indicated.[20] A large proportion of patients admitted here had fractures of the femur, and most of its other patients had severe and multiple injuries. Patients were usually sent to this ward direct

from the receiving department, but occasionally those who had developed shock more slowly also reached it from the dressing room, from the preoperative ward, or from the operating room. When a shock patient had improved and his blood pressure was rising, the chief of the surgical service determined when operation should be performed. As delay now meant increased infection or lost opportunity, such patients had precedence over all others except those with active hemorrhage. Patients who developed shock while under operation were sent to the shock ward, or, if necessary, were transfused by the shock team while on the operating table.[20]

It proved convenient to place the X-ray department at one side of the operating room and the sterilizing room at the other side. If a Bessonneau tent was used for the X-ray department there was room for dental and laboratory departments in the same tent.[20]

The X-ray ward was also close to the preoperative ward and sometimes connected with it. Its interior was darkened by black cloth or paper. Selection of patients to receive fluoroscopic or screen examination was made by the chief of the surgical service. Most patients so examined were those with fractures or foreign bodies. Clean, uncomplicated, perforating bullet wounds were not examined radiologically, as a rule, unless the missile had passed close to a bone or a joint.[25] Shell wounds, on the contrary, required X-ray examination in every case, as otherwise it was impossible to determine the presence or location of shell fragments in the deeper tissues. Injuries to the cranium were photographed both to facilitate immediate care and to furnish a record for the use of other surgeons who would attend the patient in future.[25] However, plates were used only for conditions of peculiar interest and where accurate localization of foreign bodies was desired. Whatever the method of examination employed, the radiographer made a record of his findings in a brief note or sketch on a slip which was affixed to the patient's field medical card or entered it on the card itself. As a matter of fact, the majority of patients operated upon were examined radiologically before they were sent to the operating room, though certain types were operated on without this; for example, those with active hemorrhage or those received with a tourniquet in place, and fractures that had not been splinted before admission.[20]

From the radiological department the patient was sent to the operating room; or, if no fracture or foreign body was found, and (before team service was fully developed) if early operation was not possible, to the evacuation ward.[20]

Though operating-room facilities differed considerably in the several hospitals, when possible to avoid it, not more than 10 patients were allowed to accumulate, awaiting operation. A Bessonneau tent, floored with wooden sections (transportable) and provided with a sectional table and one sectional shelf under it running the length of the tent, proved very satisfactory, but two such tents were advisable to meet emergency needs. One of these was sometimes used for minor injuries only.[20] The top of the table mentioned was used for scrubbing basins and sterile instruments, while the shelf below contained packets of gauze, towels, sheets, bandages, and similar articles, and below this, on the floor, was space for splints. The operating tent was made light-

proof by black linings with hinged window flaps. From 6 to 10 operating tables—usually 8—were spaced on the side of the tent next the long table holding instruments, leaving a 4-foot passage at their other end for litters, which were made to pass in one direction only. One or, if possible, two electric lights—one on a long cord, and each provided with a cone shade to prevent dispersion of light rays, especially upward—were placed over each operating table. Tables were provided also with slings, rigged up on wires. Each operating team used two tables, a method which speeded up work considerably, especially on minor wounds requiring local anesthesia and head wounds which required shaving of the entire scalp. Patients with abdominal, head, and chest wounds were assigned to special teams.[20] Local regulations concerning such matters as suture or nonsuture of wounds, hours of assignment, and conservation of supplies were posted, especially for the information of surgical teams temporarily assigned.[20]

Two surgically clean nurses, with all the available instruments boiled and divided equally between them, could supply any number of teams that could operate in a Bessonneau-tent ward. When each shift went off duty, and, as happened much more frequently, when a break in asepsis or other condition required, an entirely fresh layout was made.[20]

An orderly served each shift, noting on each patient's field medical card a statement of the surgeon's findings, the operation performed, and the word "evacuate" or "detain." Patients held included especially those with wounds of the head, chest, and abdomen, with fractured femur, and with shock. A copy of the note made was entered in the operating-room book, supplemented by an entry of the patient's name, his official designation, the interval between injury and operation, the diagnosis, and the X-ray report. The operator's name followed both entries. Decision as to whether patients were to be evacuated was influenced by admissions, concerning which the chief of the service kept the operating teams infoımed. The field medical cards of patients who died on the operating tables were completed and turned in to the record office.[20]

The operating room was usually in charge of an officer under whom were the recorder, a noncommissioned officer in charge of the enlisted personnel then on duty, a nurse in charge of sterile instruments, an enlisted man who received them from her for each operation, three general utility men to move patients and to hold a leg or an arm to facilitate operation, six litter bearers, one messenger, and one man in charge of sterilizing dressings. The nurse in charge of sterile instruments had a great quantity of these at hand on a table provided for the purpose, and issued them as called for.[25]

When a patient was carried from the operating room he passed the assignment sergeant, who designated the ward to which he should be taken. This was determined from notes on the patient's card—evacuate or detain—and from the record kept here of the location of vacant beds.

Sterilization apparatus was installed in a hut or tent near the operating room, but separate from it, as a rule, because of the danger of fire. This equipment approximated the following articles: Autoclaves of 24-inch diameter, numerous drums for dressings, instrument boilers, and three vessels each

FIG. 96.—Fracture ward of an evacuation hospital

FIG. 97.—The splint room of an evacuation hospital

provided with a faucet and having a capacity of 25 gallons. The last named were supported on an iron foot base and all were heated by gasoline burners. There was some variation in this equipment, the personnel of a unit sometimes showing considerable resourcefulness in extemporizing apparatus.[25]

The work of sterilization was conducted as a rule by two nurses assisted by two or three enlisted men.[25]

The wards of the hospital other than those mentioned above were for postoperative patients, for other surgical patients awaiting evacuation, for certain medical cases, and for gassed patients. In postoperative wards alternate shifts of one officer, one nurse, and six enlisted men usually were provided. In some units the operating surgeons spent eight hours a day in ward service. These postoperative wards, like others, were assigned to different ward surgeons who might or might not be members of operating teams. As a rule, ward surgeons dressed postoperative cases except when these were difficult and the admissions few. All surgeons in charge of wards carried out the usual administrative record routine, making needed notations on field cards, daily reports of transportable and detention patients, classifying transportable patients as "walking" or "litter," "medical" or "surgical," "officers," and so on.[20] This classification was made daily; in some hospitals twice a day. In certain hospitals patients were tagged for removal with distinctly colored cards.

GENERAL SURGICAL RULES

The following general rules concerning operative treatment in evacuation hospitals are based on the collective experiences of medical officers in the American Expeditionary Forces:

Preoperative Preparation

One should put in operation all methods which can be applied in advance in order to increase the margin of operative safety. The patient's temperature must have been brought back to normal, and it must not be allowed to fall as the result of exposure, wetting, or rough manipulations incident to surgical preparation of the operative field or to transportation from the receiving tent or ward to the operating table. Bring the life of the cell into the best state possible before the operation; blood transfusion may have to be supplemented by the free administration of water, per os, per rectum, or intravenously. Water must be given in advance of the operation; one can not water a cell in a moment; it takes time to do it. It takes more time to water cells when they are sick than when they are well; therefore one must give hours of time to watering the cell. The greater the degree of shock the less absorption will there be through the lymph channels; therefore subcutaneous injections of water are frequently useless and may permanently damage the tissues they compress.

The exhaustion of starvation must always be considered and relieved. Regardless of the severity of their wounds, nine out of ten wounded soldiers clamor for food before they are discharged from the ambulance. There is no logical reason why soft, easily digested warm foods should be withheld.

Soldiers with intra-abdominal lesions should, of course, be excluded from the buffet which forms so important a part of the admitting tent; practically they are the very ones who manifest no desire for food. While admitting the fact that the giving of nourishment to a patient who will shortly afterwards be anesthetized presents certain esthetic disadvantages, no harm can be caused by this custom. When one has seen hundreds of wounded men eating their fill at the buffet and then, deloused, washed up, and clothed in clean pajamas, fall into their beds and into profound slumber, from which they awaken a few hours later strengthened and refreshed for their operative ordeal, there can be no further doubt as to the best procedure to follow.

Preoperative purging should be omitted. Up to the present time no definite proof of the actual existence of intestinal auto-intoxication has ever been demonstrated. That purging induces gas formation, harmful peristalsis, dehydration, and disturbed sleep is beyond question.

The preparation of the field of operation should be intrusted entirely to a properly trained orderly, usually forming part of an operating team. Having bared the wounded area with a minimum amount of exposure of the patient's body, the dressings should be removed and the wound protected from contamination by means of a gauze sponge or wad of sterile cotton. Shaving should be gently done and the remaining lather removed with pledgets of gauze or cotton. Violent use of a brush for scrubbing is undesirable, as it uselessly traumatizes the skin; a gauze sponge saturated with soap and water is preferable. Large amounts of water or antiseptic solution poured over the operative field do no good and tend to lower body temperature through wetting of skin and drapings. The placing of rolled sterile towels or wads of cotton around the dependent portion of the field of operation will prevent or minimize the wetting of the body. Whatever solution is used should be wiped or mopped up as the cleansing progresses. Having completed the mechanical cleansing of the operative field, the gauze plug in the wound should be removed and the area swabbed with ether and painted with tincture of iodine. A dry piece of gauze or sterile towel should protect the wound until the surgeon is ready to operate.

Immobilization of compound fractures must be maintained throughout the preparation of the operative field. This is always possible when a Thomas arm or leg splint has been previously applied and slings are available over each operating table for elevation of extremities.

A hypodermic injection of morphine, grains $\frac{1}{4}$, and atropine, grains $\frac{1}{150}$, should be given by a nurse one hour before the operation, unless there has been a previous administration of the same. The operative field can be prepared without disturbing the patient's sensorium if he is narcotized; in cases associated with extreme pain the dose of morphine can be repeated.

Sterilization and Surgical Supplies

The sterilization room must be adjacent to the operating tent or barrack and should include storage of splints and sterile goods. Two teams on 12-hour shifts should be constantly on duty. Two orderlies clean and scrub the instruments; one orderly repairs the gloves and sharpens scalpels; and a nurse superintends the storing of the instruments into standard sets and their subsequent

sterilization. The size of these teams may have to be much increased if additional teams are operating. The preparing of standard débridement sets and standard dressings in anticipation of the arrival of a convoy of wounded is of extreme importance and the sterilizing room must at all times keep ahead of the demand. During the World War, a débridement set usually comprised the following instruments: Tate's straight clamps, 4; Tate's curved clamps, 8; Kocher's clamps, 4; French (terrier) clamps, 5; mouse-tooth forceps, 2; scissors, curved, 1; scissors, Mayo, 1; Allis's forceps, 3; towel clips, 4; needle carrier, 1; retractors, small, 1; grooved director, 1; scalpel, 1; needles (two of a size), 6.

Special instruments and special dressings can be added when called for according to the nature of the wounds presented by any particular case. These complementary sets should all be made up and sterilized in advance. Abdominal, amputation, craniotomy, bone and lung sets were all standardized, as follows: Abdominal complementary set: Ribau retractors, 2; self-retaining retractor, 1; deep abdominal retractor, 2; sponge sticks, 2; intestinal clamps, straight, 2; intestinal clamps, curved, 2; Tate's curved clamps, 6; needle holder, Mayo, 1; tissue forceps, 1; Blake suction tip, 1; needle, cutting, Martin, 1; needles, Mayo, 2; needles, Ferguson, 2. Amputation complementary set: Amputation knife, medium, 1; amputation knife, Catlin, 1; saw, 1; Gigli saws with handles, 2; lion-jaw forceps, 1; retractor, 1; metacarpal saw, 1; rongeur forceps, 1. Craniotomy complementary set: De-Vilbiss with blade, 1; drill with burrs, 1; bone punch, 1; chisels, 2; trephine, 1; Doyen blunt needle, 1; grooved director, 1; alligator forceps, 1; Gigli saws with handles, 2; Luer syringe, 30 c. c., 1; dura elevator, 1; brain spatula, 1; pad of French needles, 1. Bone complementary set: Periosteal elevators, 2; spoon curettes, 3; mallet, 1; lion-jaw forceps, 1; bone-cutting forceps, 1; gouge, 1; chisels, 2; sequestrum forceps, 1. Lung complementary set: Costotome, 1; lung retractor self-retaining, 1; lung forceps, large, 1; lung forceps, small, 2; lion-jaw forceps, small, 1. With each set of instruments the following standard dressings should be issued:

Article	Number	Size, inches	Quantity of material
Wipes or sponges	30	4 by 4	6 yards gauze.
Do	25	2 by 2½	3 yards gauze.
Dressings	6	4 by 8	Do.
Bandages, gauze	2	3 or 4	Do.

In addition to the above, the following dressings are called for in special cases: Dakin pads, one-half yard gauze; gauze rolls, five yards.

The above issue of instruments and dressings will prove adequate except in a few cases of multiple wounds or very large wounds. Additional supplies should always be available.

QUALIFICATIONS OF EVACUATION HOSPITAL SURGEONS

War surgery is similar to civil traumatic surgery, except that many of the wounds encountered are more severe and especially more lacerating than usually obtains in industrial surgery. A civilian surgeon thoroughly familiar with his routine work merely has to adapt himself to military conditions and necessities.

The frontline surgeon is no longer able to choose his own surroundings; he has to make the best of those in which his lot is cast. Of the wounded in detail he can see little; he sees them only *en masse*. The *sine qua non* of a good military surgeon is to submerge in a large degree his individuality as promptly and as thoroughly as possible. To succeed in surgery at the front a man must possess adaptability, good powers of observation, mental alertness, and judgment. He must not be carried away by a desire for elaborate and time-consuming technique, which will cause him to prolong an operation and complete all the surgery in one sitting when only the most necessary work should be done, the rest being left for the surgeons at the base. To get the patient off the operating table in as good a condition as possible and to remove any cause for further complications are the primary desiderata in surgery at the front. It goes without saying that a good physique is necessary to withstand the privations and tremendous pressure of work that one is liable to be subjected to in the zone of the advance, and here the youthful surgeon, other things being equal, is to be desired. Above all, perhaps, the surgeon at the front must not have forgotten his gross anatomy for he can not safely explore a region for a foreign body or attempt the preparatory treatment of a lacerated wound associated with a compound fracture without its aid. Next in order of importance is a good practical acquaintance with infections; not the bacteriology of the laboratory and the microscope, but the clinical signs, the appearance of the tissues and their behavior when invaded by infectious material. He should know the danger areas for gas infection and be able to distinguish between localized gas infection and the progressive type which rapidly becomes deep and malignant and demands bold and radical surgery. Each surgeon must yield his personal idiosyncracies and desires in the common interest, and use standard sets of instruments and standard sets of dressings, which permit a marked reduction in the general service. He must possess, or be capable of evolving, a rapid though safe technique in order to keep pace with the stream of wounded. Finally, each surgeon must train himself to operate as much as possible by the "hands-off" method, i. e., to operate without needlessly contaminating gloves or sterile gown. As a rule, in active evacuation hospitals only two pairs of gloves and one gown will be issued to each surgeon per period of duty; hence the necessity of rapidly acquiring the above technique. Gloves are easily sterilized, without removal, by scrubbing with soap and water and by immersion in 1 per cent of lysol solution, but the gown must be kept free of the operating table and the undraped portion of the patient throughout the surgeon's period of duty.

GENERAL PLAN OF OPERATING SCHEDULE

Regardless of the terrain, the general arrangement of admitting tent, shock room, sterilizing room, X-ray room, and operating room should be such as to avoid any retracting of steps from the time of admission to final disposal of the case in shock room, ward, or evacuation tent. This essential system has been aptly termed the "one-way system."

Each operating team, composed of one operator, an assistant, an anesthetist, a "sterile" nurse, and an orderly, will have to work in day or night shifts which vary between 6 and 12 hours each. The orderly prepares the patient for

operation and assists his team as directed. Another orderly for every two teams should also be on duty to record data concerning the operations and to maintain the operating room blotter, so that a record may be kept of all operations performed in the hospital. In each operating room there should also be one enlisted man, scrubbed up and wearing a sterile gown and gloves, who obtains from the nurse in charge of all the sterile supplies the necessary instruments and dressings for each operation. One utility runner for every two teams will assist in holding legs or arms (where pulleys are not utilized), in changing the positions of patients, or in any other such duties as may arise in the course of or prior to an operation. Whenever possible, an orthopedist should be given supervision of all splintings.

Each team should have at least two and preferably three operating tables at its disposal. Thus the surgeon finishing the important part of one operation may leave the remainder to his assistants while he cleanses his gloves and proceeds to the next table to find the next patient whom he finds anesthetized, his wound area surgically prepared, and protected, and the necessary instruments ready. The third table is used for splinting and will be found to be a great time saver. As one operation nears its end, the anesthetist is replaced by the orderly or nurse who, under the supervision of one member of the team, holds the patient's jaw forward and adds a few more drops of ether, if indicated. Unless this system is strictly adhered to, much time will be needlessly wasted in the operating room. A properly organized system will easily quadruple the operative output of a surgical team—an all important item during a heavy battle.

Six or more litter bearers should be on duty in 12-hour shifts to carry patients from the X-ray room to the operating room and thence to the ward or recovery room for critical cases.

The constant flow of patients should be under the direct supervision of the admitting officer—now become director of surgical material. As soon as a convoy has been disposed of he should take position near the entrance to the X-ray and operating rooms, to prevent undue congestion at any point.

RULES OF GUIDANCE FOR OPERATING TEAMS

For the general guidance of operating teams the following rules were posted in some operating rooms:

General surgical rules for the information of operating teams:

Débridement.—Débridement should be thoroughly carried out in preparation for delayed primary closure. Excise a minimum amount of skin. Whenever possible avoid transverse incisions of skin and muscle. Double funnel débridement in deep penetrating wounds of extremities is preferable to one way operation. Leave no tabs of fat, muscle, or fascia. All high explosive and shell fragment wounds and those due to explosive projectiles must be freely opened and conservative débridement carried out; they should not be sutured. Dakin tubes should be established, if necessary, and gauze lightly inserted. Vaseline gauze on skin for protection. Exceptional cases of exposed blood vessels, head, face, chest and joint wounds may alter the above rules.

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Wound suturing.—All wounds of soft parts to be left open, except: Scalp and face; chest; abdomen—counter-drain when necessary; joints—close capsule. Do not suture skin.

Wound dressing.—Final dressing should preferably be a gauze fluff soaked in Dakin's solution and placed so as to keep the wound open. Some surgeons swabbed the wound out with ether, followed by tincture iodi; others used tincture iodi alone. Conservation of gauze in wound dressings.

Drainage.—Penrose rubber tubing for through-and-through drainage. Mosquito netting soaked in ambrine to avoid plugging wound.

Amputations.—Consultation before all amputations. No guillotine amputations. Conserve all skin possible and as much of the limb as possible, i. e., as safety will permit. This is of especial importance in amputation of the forearm. Large vessels should be carefully dissected free before ligation. Nerve trunks should be severed high.

Compound fractures.—All compound fractures should be approached through free incisions which are to be left open. Loose pieces of bone without periosteal covering should be removed. No wire or bone plates should be used for fixation. Drains must not be placed against bone fragments.

Joints.—Gentle manipulation at all times. Preservation of joint except in the presence of extensive comminution.

Nerves.—Surgeons must examine carefully before operation all wounded extremities for loss of nerve function. Nerves should be sutured with fine silk and then covered with fascia or muscle.

Perforating bullet wounds.—Perforating bullet wounds without extensive bone comminution or injury to important blood vessels or nerves do well without operation. If they are to be evacuated, however, they must be débrided to omit the 5 to 10 per cent of infection that occurs.

Responsibility of the surgeon.—The surgeon is responsible for everything that happens to the patient from the time he is placed on the table until he is evacuated from the hospital. If the patient is in poor condition after the X-ray examination, the surgeon is not expected to operate contrary to his own judgment. If doubt exists, a decision may be arrived at in consultation.

Records.—Operations must be recorded upon the completion of each case. Always state in the record that the foreign body has or has not been removed.

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CHAPTER V

COLLECTIVE SURGICAL EXPERIENCES AT THE FRONT AND AT THE BASE

AT THE FRONT

At the eleventh session of the Research Society of the American Red Cross in France, held November 22 and 23, 1918, a symposium was had on the problems of the surgeon in relation to the area of the advance, American Expeditionary Forces. In attendance at the conference were representatives not only of our Medical Department but of the medical departments of our Allies as well. Since the opinions that were expressed, in reply to previously prepared queries, were given almost immediately subsequent to the cessation of hostilities, they necessarily were based on all the experience, under battle conditions, it was possible to obtain during the World War, and in some instances, as in the case of the medical officers of the allied armies present, the background for them was the period of the war 1914–1918. The report in full follows.[a]

CONFERENCE ON PROBLEMS RELATING TO THE AREA OF ADVANCE

General FINNEY. This meeting was planned some two months ago, at a time when we were in the midst of great activities. To-day, fortunately, the war is over, but I hope we will find enough to interest us in considering some of the points that were under discussion during that period. I am glad distinguished representatives of the British, French, and Italian medical corps are here. I am sure they will be willing to give us the benefit of their wide experience.

The transactions of this meeting will be kept in some permanent form, so that in the event of another war—which God forbid—we will have at any rate a record of the combined experiences of those who are present this morning, composing a scientific organization such as this.

Members of the committee visited a number of hospitals to ascertain what problems they had met in their work, and what questions had specially troubled them, upon which they would like to have the opinion of others. These questions voice the thoughts and problems of many of the hospitals and medical men of the army.

As clinicians, we have primarily to deal with the patient, but many problems involving the care of the patient are inseparable from those of administration. Our questions this morning largely concern the latter, and necessarily, therefore, administrators are in a position to give the best information.

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[a] Research Society Reports. The eleventh session of the Research Society of the American Red Cross in France. Nov. 22 and 23, 1918. *War Medicine*, Paris, 1919, ii, No. 7. Published by the American Red Cross Society for the medical officers of the American Expeditionary Forces.

Division A. **What should be the function of the battalion aid station?**

B. **Is it desirable to continue the regimental aid station?**

It will be well to consider these two questions together.

Lieutenant Colonel TURCK. One thing that we have to consider is that it is very unfortunate that our army has not had more open warfare, because we are inclined to consider the battalion aid post and the regimental aid station from the standpoint of a fixed division, where it is possible to have all the equipment necessary, to provide plenty of litters, plenty of blankets, and plenty of hot water. But the one thing we have worked on, and which necessarily will have to be worked out in open warfare, is: What should the medical officers do in a rapidly advancing area?

When a division is advancing, no aid post is possible. When troops are going forward the only thing for the battalion aid men to do is to carry their equipment on their backs, to give morphia, apply first aid, and go on farther. It is impossible to get through shell fire, machine-gun fire, and gas to install an aid station, except in a shell hole or a captured dugout; you can't take your equipment with you; it is an impossibility. There is a possibility of using Japanese push carts, and in a rapidly advancing division that is all the men can do practically. I will read you something based on the scheme of Colonel Grissinger. * * *

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The fixed station is very little trouble to handle, but when troops are advancing it is simply a question of first aid, giving morphine, putting on dressings, etc., and going on with the troops. Also, the men will be divided; you will perhaps find two wounded men of each company, and the battalion aid officer must attend to whichever is suffering most. Under shell fire you can not stop to put on splints. In talking with Colonel Grissinger we thought that we could perhaps use a splinting party from the ambulance—collect the men as well as possible and send on a splinting party with splints and blankets, and supplement the pack roll with supplies sent up by ambulance, though frequently there are no roads. Then most of the splinting could be done along with the litter section of the ambulance.

I have just one word to add about the regimental aid station. I certainly think it is a mistake to have a regimental aide station because of the number of men. More can be done if the men can be taken to a central station, but very frequently they can not; they will stay in shell holes. I may mention one instance, in the Argonne, when our troops were advancing and at times retiring. The regimental medical officer took care of the wounded in shell holes for 36 hours, and he carried them back after crawling from one shell hole to another. When organizing an aid station we do not consider all these things, and we do not always realize that it will be inpossible at times to get the men there.

Colonel PEARSON. We have been with the 5th Division, and during the summer we operated first in the Vosges, then at St. Mihiel, then north of Verdun, and lastly across the Meuse. In each part we had entirely different positions, and in each plan of attack the position of the troops, the artillery, and the machine guns were entirely different, and the scheme of evacuation of

wounded and care of the men, the disposition of the battalion and regimental aid stations and infirmaries had to be adapted to the terrain and military situation at that time; so we can not quote any fixed law or rule as to where the aid posts will be, what they will take care of, what will be the function of the regimental aid station, etc. If you are working with the infantry and advancing with a wide sector of the front, you may have one battalion in reserve and one for a certain part of the sector, you may have a whole division on a front of 3 km., or you may have a division spread out over 30 km. in another place.

I want to give tribute to the men who have served as battalion surgeons; to my mind they are the most important link between the Medical Department and the patient. Our function is to take care of the troops, and it is through the regimental and battalion aid surgeons that we come in contact with our patients. These are the men who have been going with the Infantry right forward, who have been sleeping out in the mud, who have suffered all the hardships that the troops have undergone in the advance, who have worked under shell fire, under rifle fire, under machine-gun fire, and they have the admiration and respect of the men working with them. These are the men who have kept us in touch with our patients and who have given the Medical Department what standing it has with the fighting line. Our soldiers have admiration for the regimental and battalion surgeons, as they have for the ambulance section and for the hospital surgeons.

We have not had enough battalion surgeons, because some of these men have been killed. The dental surgeons assigned to the divisions have also been right out on the front doing first aid work, and several of them have been cited for conspicuous courage under fire.

The battalion aid station does not amount to much as to material; you must bring up what you can. In the St. Mihiel sector we had only one road, and that was soon blocked by heavy artillery, large caterpillar tanks, and the infantry, and the regimental aid stations were pitched 25 km. from the rear. The men took the material up on litters. One night, during the advance, the troops had to pass through woods, and a great deal of material was lost, so that in the morning, when we went over the top, the sanitary troops of the line carried what they could in their belts and in sacks, and with what they could climbed out of the trenches and through the barbed wire. The supply officer of the division sent on splints, etc., by the first ambulance that went through.

Primary aid must very often be carried on the men's backs; with trenches to jump, barbed wire, then more trenches and more wire, it is perfectly obvious that no pack mule can get through and no medical cars either. There were no roads; all roads had to be filled in by the engineers as we advanced. If we could not use the main roads, why did we not go through the fields or by the side roads? But neither mules nor cars could go through 11-foot trenches, shell holes, or barbed-wire entanglements. The regimental aid station takes what it can carry, and is supplemented by the first ambulance to get through the lines.

In the battalion aid station, conditions are sometimes different. One battalion goes on first and lies down on the grass, then another goes through and beyond, so they go up on the same line. Then you must put the battalion aid station where you can, which makes an entirely different situation. The ambulance dressing station would be able to get some ambulances to the regimental aid station, and later in the day to the battalion aid station. Conditions have to conform and vary with the conditions of attack.

When the regimental station gets to a place where it can stay for a week or so, it requires a certain amount of records. Records of the men and of the personnel must be kept, and also Form 4. You therefore need a typewriter and some office equipment. There is also the question of transporting a certain quantity of material and supplies. The form of equipment for transporting regimental and battalion supplies is quite inadequate. The best solution for that problem would be to have a Ford ambulance allowed to each battalion surgeon, which would take his material as far as it could go, and if there is no obstruction the ambulance could run to the first-aid dressing station and evacuate a few of the wounded.

With regimental infirmaries we are allowed one wagon which carries part of our supplies, but not as much as we need. There is also no provision made in the tables of organization for the transportation of supplies for the dental surgeons; there is nothing to carry their chests on. Each regiment should be given one truck to carry supplies. For the small infirmary or dressing station, I would recommend the substitution of the French tent for the present tent with short poles; the small type of tortoise tent can be carried on an ambulance and give sufficient room for the battalion needs.

Colonel Cummins. I think that we all know what ought to be done when fighting trench warfare—that is quite simple. But a very interesting and difficult problem raised by the first speaker is as to what ought to happen during open warfare. I think that under conditions of moving warfare one should not talk so much of the location and function of the battalion aid post as of that of the attending medical officer. It is he who represents the medical aid of the station, and his place is a shifting location. One principle ought never to be forgotten, and that is that the first duty of the battalion medical officer is to make known his whereabouts. He can not go constantly running after the battalion; he must locate himself and let the field ambulance and the battalion know where he is, so that he can be sent for. The battalion will break down at a certain point and have casualties; it must then be possible for the battalion commander to communicate with his battalion medical officer.

The battalion medical officer must make arrangements to get information as to where the wounded are, and then go forward and deal with them—in a shell hole if necessary, but he must let people know where he can be found. I have had this difficulty myself and I know perfectly well that the first thing is to be located, so as to be easily found.

In regard to supplies, the field ambulance must help out the battalion medical officer. The field ambulance commander, under orders of the divi-

sion surgeon, must always send ambulance detachments to cooperate with the battalion medical officer, and to bring up the field stretchers. Though these are intended to bring the wounded back, they can be used to run up dressings and other things to the place where the battalion surgeon is.

The first duty of the battalion surgeon is to try to keep in touch with the commanding officers of the field ambulance and of the battalion.

General FINNEY. C. **What should be the location, capacity, and function of the ambulance dressing station?**

Lieutenant SUTTON. In dealing with the ambulance question, a method which was first mentioned by a British colonel was adopted in a number of divisions in our service.

Assuming that a division would have a triage, the ambulance corps would be located wherever there was a good place and good hard standing for the ambulances, because in the forward area there is a lot of mud and the ambulances must be kept in good condition. A motor repair section is stationed a little before each road crossing, and whenever possible one is worked up as a post-battalion aid station. The system is so worked that as each ambulance comes through the rear, the patients are not changed from one ambulance to another, but as this ambulance passes the next simply goes back and takes its place. In this way you get an efficient use of the ambulances by the method of circulation, the personnel gets a chance to rest, and there is time to clean and repair the car. In some divisions especially, it is remarkable how clean the ambulances have been kept at all times.

Of course, the ambulance company has not only the side of transportation, but it has the question of ambulance dressing stations. The number of dressing stations is determined by the type of sector and type of warfare. It has been found especially satisfactory to have two dressing stations for a divisional sector, and in a rapid advance to have only one functioning at a time and the other moving forward and setting up; if possible another can be packed up and ready to go forward.

In crossing No Man's Land, where the line has been fixed for some time, it frequently happens that a big road is blocked, due to mining or the destruction of the rails of communication; these mines explode after a certain time, and if you can get the dressing station across before they blow up, it gives you time to care for the wounded.

Lieutenant Colonel TURCK. I only wish to mention one point, and that is that when the roads are entirely blocked and no ambulance can move, no ambulance scheme will work out. You must then look out for other transportation—trucks, ammunition trains going up, etc.—anything that is going forward. You can fill up trucks that are going back; mule ambulances can be got along where others fail to pass, and worked from the ambulance dressing stations, they have done a good deal of fine work. When the roads are blocked and the ambulance service breaks down, if there is any kind of open territory you can depend on mules and thus relieve crowding of the dressing stations. It is a matter of utilization of every bit of transport available—mules, railways, munition trains, push carts, etc.

General FINNEY. This question is largely one of transportation, and it will be interesting to get the experience of the British Army because their conditions were different. We had a great deal of mud, but not as much as they had.

Colonel CUMMINS. As I had to go through this experience I know something about transport. I think that we must retain all transport, including mule ambulances. I think the old ambulance wagon is not very good; it is much too heavy. What I would like is a little, light, two-horse ambulance. We have a light ambulance wagon that can go wherever a gun can go; it is very useful, and I think it ought to be supplied to the infantry field ambulances in the future. We must have seven motor ambulances per field ambulance, and they have been a very good replacement for the large, heavy ambulances of past days.

I would like to see at least three light ambulance wagons to every division. It seems to me that you could use horses if mules are not available, but you want to get good pack saddles that will take stretchers. Stretchers are important to get forward, but they are not easy to carry. A good pack saddle has to be well thought out. I think the field ambulance of the future should have a pack transport; at any rate I am a believer in a few horse-drawn vehicles and means of utilization of pack transport when necessary.

General FINNEY. D. **What should be the function, location, and control of Field Hospitals?**

Lieutenant Colonel LEE. I have been with the 2d Division for eight months and we worked out the following system:

First. Hospital reserved as triage, and specialized in triage.

Second. Gas and medical hospital with 200 to 250 beds.

Third. Hospital for wounded. This is organized as a mobile hospital for seriously wounded.

In our division I think this worked out very well. The triage hospital was very far forward; the men working there were specially trained in splinting, etc.; in the medical and gas hospital we had the men of the division who were most adapted to medical work, and for the seriously wounded hospital we had trained surgeons.

The ambulance companies were not used as triage. The entire front line of the field was handled by an ambulance company. I have always felt that if the mobile field hospital is properly organized and supervised, it can get where it is wanted very quickly. From the standpoint of the troops it helps the fighting men materially to know that the same group is always waiting for their division.

General FINNEY. As I understand them, conditions in this war are entirely different in regard to field hospitals from conditions in preceding wars.

In our army at the present time no operating is planned to be done in the field hospital, but in exceptional circumstances it has to act as a mobile hospital.

There is a good deal of discussion at present as to the equipment of the field hospital. Should there be one or two field hospitals kept for emergency surgery? In rapidly advancing lines everyone appreciates this advantage.

It has been pointed out in this war that if you have facilities for operation, the temptation will always come for those facilities to be used when it may be unnecessary. Is it for the greatest good of the greatest number to have field hospitals equipped to do major surgical work, or to keep them entirely out of surgical work and utilize the mobile hospital attached to the division or corps? That is a very important point.

Lieutenant Colonel Clinton. My ideas are based exclusively on the fact that we have two distinct types of warfare. In a big push no scheme works perfectly, and it seems that the establishing of nontransportable hospitals or mobile hospitals is purely a matter of transportation and a matter of the number of wounded. When some hospitals have 1,400 patients come in in a period of four hours, all they can do is triage work, and it was observed that the most satisfactory triage of patients was done in those hospitals that attempted no operative work. The first cases that came down improperly splinted came from an ambulance that started to do its own surgical work. It is quite enough for field hospitals to do triage work.

General Wallace. As General Finney has said, this is a very important point. In the British Army we started with the idea of doing operations in field hospitals, and these were equipped for that work and had surgeons. One of the wisest things our army did was to decide that no surgical operations should be done at the field ambulances, but at the casualty clearing stations. Taking all in all, I believe the greatest good is done for the greatest number by doing the operating in the casualty clearing stations and allowing the field ambulance people to do fetching and carrying work. I always tell the men that really they are doing work which is as important as that of the surgeons back in the clearing stations. Surgeons are felt to be very scarce in the army, and if they are concentrated in the casualty clearing stations they will do more work.

In stable warfare I believe in putting teams into field ambulances and making proper forward operating centers. In winter time, especially in the case of shattered limbs, I believe that a team sent to a field ambulance will do good work, but that in general it is best to keep surgeons in the clearing stations.

Colonel X. In an advance movement, and especially in cold weather, the function of the field hospital is often to provide shelter and cover for the men, because if they are left out in a heavy frost overnight many of them will be dead by morning. If they are sent away to the evacuation hospital the distance is often very great. One of the longest distances recorded to get men to an evacuation hospital was 75 miles. If patients are put on ambulances and carried that distance, some will be dead before getting to the hospital.

In our division, the field hospital went forward, following as closely as possible behind the troops. It was necessary as the troops advanced to push the first hospital up. It should not, however, be placed at cross roads where it is liable to be under shell fire. We had 1,200 cases evacuated during a period of 14 days. We had one operating team and one shock team, and we found that we were able to take care of two, and in some cases three, divisions. The only type of operating done there was in cases that would have died if they had been taken to an evacuation hospital.

The gas hospital was set up where there could be shower baths, etc. One of the most important stations for slightly wounded ceased to exist when we had triage hospitals. The slightly gassed cases should be eliminated, because intoxication by gas is a matter of degrees, and many of the slightly gassed men can continue in the line. In one instance, 3,500 men sent as gas cases were sent back.

It is an absolute necessity to push hospitals forward as quickly as possible to take care of the elements making the attack. We found that we could usually get the hospitals moved up at night. One of the first units to cross the Meuse was a field hospital, in order to provide shelter for the men who had made the attack during the day.

Lieutenant Colonel X. I don't really feel that I had better say very much, as my personal experience is not sufficient. However, I feel very strongly that in field hospitals and all advanced formations every preparation should be made for the care of surgical shock. The desirability of having better preparations for the care of surgical shock in triages and everywhere else is very great, and what has been said as to the value of the field hospitals for keeping patients warm is extremely important.

Lieutenant Colonel Poole. One feature that I feel very strongly about is that there is a great leaning toward doing operative work in field hospitals. I have seen operations done on the knee joint, on the cranium, on fractured tibias, and many other cases which could have been sent to better equipped hospitals.

Triage hospitals generally have not the personnel, the equipment, nor the facilities for hospitalization for a proper period to give patients the best chance for recovery. This applies to individual cases; the greatest good for the greatest number is very apt to be overlooked. Surgery in general should be done by pushing up some sort of small mobile unit as near as possible to the triage, where the work can be done far better than in any field hospital. Field hospitals should concentrate on the treatment of shock and on triage.

At Mobile Hospital No. 2, it took 20 minutes for five medical officers to sort out from two trucks the seriously wounded cases which they should take. Loss of time is avoided by putting the slightly wounded in one truck and the seriously wounded in another. Efforts should be directed towards triage and treatment of shock, and operating should be done by small mobile groups pushed up as far as possible.

Lieutenant Colonel Vaughan. Personally I feel that as our field hospitals exist at present there is no call for them and no place. They should be kept for gas, medical, and triage work. We can not lay down any definite rules as to what type of surgery should or should not be done in field hospitals. At our hospital we had one tent as a triage, and four other tents placed as follows: (1) Gas and medical; (2) walking cases; (3) stretcher cases; (4) slight stretcher cases.

Ambulances coming in went to the proper tent, from which the patients were evacuated to proper hospitals.

But when the roads became blocked, all we had was one tent for shock cases, associated with another tent from another hospital for nontransportable cases. The work there was work that had to be done to save life.

In one instance 80 per cent of the cases were gas infection or slightly wounded cases. When this happens, our function changes. The slightly wounded should be operated and the seriously wounded left alone. The time element is really the important factor.

A small mobile surgical unit should be attached to every division in open warfare. The type of large casualty clearing station used in the French, British, and Belgian armies is especially valuable in fixed warfare, but a small unit can be put up in four to six hours, and can take care of troops who would die from gas infection if there were no means of taking care of them.

Colonel Brooks. One point is very important; everyone has spoken of the importance of proper triage of gassed and medical cases. One of the greatest faults in the triage and field hospitals is that influenza, measles, and scarlet fever are distributed among gassed cases. You should separate the gassed cases which are susceptible to infection from infectious cases and also from the slightly wounded. This should be carefully done. The evacuation hospital is the worst center of infection; the next is the improper triage and field hospital.

In regard to shock cases, I do not believe that they fall properly under the line of medical treatment; this is a surgical proposition, and I believe the surgeon is better prepared to take care of this work and that he wants to do it.

I think the shock cases belong to the surgeon, and the medical men should recognize that this is true.

Lieutenant Colonel Lee. In the last offensive the hospital for seriously wounded men was located 18 km. south of the line; for 36 hours we had no evacuation hospital behind us at all; no ambulances, no trucks. The field hospital handled 987 patients and operated 335 cases. No one deplores more than I the doing of surgery in field hospitals by inexperienced men, but if a capable surgeon could be placed to teach adaptable men to do surgery, good work could be done.

On one occasion our men worked 20 hours at a stretch, and there was no hospital available behind us. We have never done head cases or spine cases; these should go back. We have done abdomens and chests, and compound femurs in shock, also bad multiple wounds. If we were to have gone on for a number of months it would have been advisable to have a small mobile unit attached to the division.

General Finney. This is a very important point. In the Second Division they have put up a wonderfully good demonstration of what can be done in a field hospital. The only question in mind is whether this was an individual thing—whether it was because Colonel Lee and his unit were working together with the division surgeon that they did such splendid work, or whether it is a demonstration of what we all ought to be able to do.

At the present time I am not convinced that the same idea could be transplanted and found to be for the greatest good to the greatest number; it has worked there but it might not work as well elsewhere.

Colonel X. There is one point of danger in this scheme; that is, that the field hospital will be converted into a triage hospital or a specialized hospital. It seems to me that our field hospitals should be trained to do everything possible—medical cases and surgical. There is danger that the gas hospital should do nothing but gas cases and the surgical hospital nothing but surgery.

Given a division that has a front of 30 or 40 km. there will be four or six hospitals for different cases. Another sector of 10 to 12 km. will have one hospital, with a gas hospital acting also as triage. We can not always pick cases and send them to specialized hospitals. With a division that is advancing, we should group hospitals and have them do the triage, but we should not train field hospitals along any one line. It makes no difference whether you call it a mobile, field, or evacuation; all depends on the men and equipment. If there is a good surgeon at a field hospital, that hospital will do good surgery. I should prefer the field ambulance as the British have it; our field hospitals should be *generally* trained, not *specially* trained only, and should be ready to do emergency work of any kind.

General Makins (British). I think the last speaker has touched the great point—military surgeons must be general practitioners. It is quite true that you may have special units for special work, but the surgeon ought to be ready to take anything that comes into his hands.

Colonel Cummins. I want to indorse the remarks made by the last two speakers. I feel quite certain that no divisional unit can avoid being ready to do anything that comes along; it must be general and not special.

Certain points require special study. The best field ambulance I had had specialized in the immobilization of fractures, in the arrest of hemorrhage, in the feeding and warming of patients, in dealing with shock cases, and in triage and clinical work. I say clinical work because it is a most important matter to a divisional commander to know what becomes of the wounded and sick that come down the line. Those are the general subjects on which field ambulances ought to specialize.

I believe our field ambulance ought to be identical with your field hospital.

General Bowlby. I have listened to this discussion with the greatest interest, but I want to say that it is impossible to lay down hard and fast rules and regulations. Personal initiative is the thing to which a great deal must be left; conditions vary with the times. What is right one time is wrong another time. While fighting is going on it is most important to pass people through as rapidly as possible to the rear. In cases where the line is fixed and the fighting not very heavy, it seems to me that the arrangements made in the British, French, and American armies are very simple and good; the difficulty comes in where there is a very heavy crowd of wounded.

Our feeling is that triage had better be done at the casualty clearing station. Don't let anyone worry the men and examine them too much; pass them on; give them to the casualty clearing station, or your evacuation hospital, and there let their fate be decided. Is a man to be retained for operation, or is he to be evacuated? The sooner you get the men to the evacuation hospital the better, and the heavier the fighting the more necessary it is to get the men there as quickly as possible. The object of the field ambulance is to have the

patients dressed, examined, and passed on. There are cases where it is advisable to do operations there, but the point of view to keep in mind is that when you have operated a man you have not finished with him, and if you have no way of caring for him afterwards it is better not to do anything; you are not doing him a kindness by operating him if you can not give him aftercare. It is necessary to have the man under favorable conditions and where he can be retained after operation. The field hospital may have to be moved and patients moved with it who are much better not moved.

In a small manual published for the guidance of our surgeons it was advocated that no operations should be done at the field ambulance except arrest of hemorrhage and removal of badly smashed limbs. This is essential. Under these circumstances you may require resuscitation teams, and we have put them lately in field ambulances to enable these operations to be done more thoroughly; but whenever a patient can be evacuated he should be sent to a casualty clearing station. It is essential to free the field ambulances and not block them.

On the 8th of August the Fourth Army began a large move, and within three weeks we had moved our casualty clearing stations thirty-four times. There is an idea that an evacuation unit is a fixed unit, but it is not. If you say you must move the whole hospital, it becomes an impossibility; but you can take a section of the casualty clearing station with operating teams and a sufficient number of staff to deal with 300 to 400 patients and put them forward. Put them in the field ambulance and there they can do the work, and while they are working the field ambulance can move up. There is too much of a habit of talking of the C. C. S. as an indivisible unit; some of the surgeons can be moved on to aid the staff of the field ambulance. If you supply operators from the C. C. S. and reestablish the C. C. S. in detail—not all at once—the thing is not impossible.

One of the greatest difficulties in our advance was the transportation of the C. C. S. forward, or bringing patients back. Our chief difficulty came from the number of canals with bridges blown up. The C. C. S. was often ready to go, but had no opportunity of moving on because of the pushing up of military material. But when we could not move it as a whole we could move sections of it and reestablish it on the other side of the canal. If we look at other parts of the world where the war has been going on, we will find other difficulties which we have not encountered. Our conditions were entirely different from those of the Italians in mountainous regions.

The general principle is to get wounded back from the forward areas as soon as you can. Do not operate unless you can look after the cases subsequent to operation. If you insist on operating a large number of cases, many of whom will have to be moved, you will lose many lives.

Colonel Crile. **Shall evacuation hospitals be specialized hospitals or not?**

General Wallace. As far as the front area goes, I think that on the whole every clearing station should be equipped in the same way to deal with every class of case. I quite appreciate the benefit of having hospitals for head cases, abdominal cases, etc., but this means great care in arrangements that the staff at the abdominal hospital has got adequate work; the same thing at the chest hospital, etc. In a battle you can never prognosticate the proportion of different

cases which you have; consequently, if you separate them, you are apt to get one hospital very hard worked while another has nothing to do at all. This is the surgical point of view. From the administrative point of view, the difficulties of evacuation in the front area are extremely great, and I don't think it is fair under those circumstances to put an extra burden on people who are already overworked. It is much better, therefore, to equip hospitals so that they can deal with every class of case and let evacuation go along on quiet lines, but from what I see I really think that at the base there is great scope for specialization, for there you can always assure an even flow of cases, and the personnel is always fully equipped.

Lieutenant Colonel CANNON. The disadvantage that comes from specialized hospitals was demonstrated at St. Mihiel. There, one hospital was set aside for very badly wounded, that was not farther away than the other hospitals but was quite separate from them, with the result that no provision was made in the way of donors for blood transfusion. Blood was badly needed, and there were no slightly wounded or gassed men from whom blood could be obtained for these cases.

General WALLACE. It is not really a question of specialization, but a question of separating walking wounded from more seriously wounded. In the British Army we put aside one station for walking wounded; they can be dealt with by a small staff and quickly sent away. From a surgical point of view the great object is for a hospital with seriously wounded not to have too much work. One can't help being struck by the air of calm in a station dealing only with serious cases.

Colonel CRILE. **Is it advisable to establish a pool of medical officers and nurses to supply emergency personnel when needed, and to render possible the utilization of all personnel at all times?**

General WALLACE. Up to quite recently the fighting has only really involved one or two armies, and our armies were asked: "What is the minimum amount of personnel that you can do with, if the army remains quiet?" Directly one or two armies got involved, the Medical Department knew what personnel was needed. Surgical teams were supplied and were moved into the fighting area. There was no definite pool, but they knew what other armies could spare.

General BOWLBY. I think the experience we had at the front is that when everything is quiet there is no objection to establishing special hospitals, but when operations get active we can no longer separate head and lung cases, and every C. C. S. must be prepared to take, in heavy fighting, everything that comes along. In times of quiet it may be distinctly advantageous to the patients to have specialized hospitals.

Colonel CRILE. **What is included among nontransportable cases? Suppose we say cases of hemorrhage, shock, wounds of the chest, as a beginning, what other cases should be included?**

General BOWLBY. I think all completely smashed limbs should never be removed from the field ambulance.

Colonel CRILE. **If there is a sufficient number of hospitals shall one mobile hospital be set aside for the care of the walking wounded?**

Lieutenant Colonel JOHNSON. I think the mobile hospital is such a valuable unit that it should not be used for this work; it should be put to the use for which it was intended, and not used for walking wounded.

General BOWLBY. In the recent advance of the First Army there was a walking-wounded hospital and three others. I think it very desirable to have a walking-wounded hospital in the same direction as, or beside, the other hospitals. It enables a string of ambulances to go in the same direction, and a given ambulance car might deposit the walking wounded at one place and other patients at another place. I remember seeing a walking-wounded officer with a small wound on the outer side of his thigh. I was asked to see him because of a swelling, and I found that he should become a lying patient. To distinguish between walking and lying wounded you need extremely competent surgeons. Out of 20 walking wounded, usually at least 1 ought to be taken to the hospital which deals with other cases. Often a large number of soldiers will crowd onto a light railway or van in order to get away, and if three or four lorries carry away walking wounded, men will get on who should be considered as lying wounded. In case of crowding a hospital for walking wounded should have a train attached to take away the men as soon as possible and relieve the C. C. S. Of course, the patient should not be taken a great distance. A large number of walking wounded are always the first to arrive, and they occupy the time and the operating theaters in such a way that when the seriously wounded arrive a large number of cases are in front of them. If walking wounded can be put in a particular train and sent to another area, you relieve you own staff and bring into work a large number of officers at base hospitals who otherwise would have nothing to do. With large numbers of wounded we have endeavored to have temporary ambulance trains and pass on the walking wounded to the base, where they will arrive soon enough for their wounds to be carefully treated. I think that when making provision for walking wounded you should also make provision for special cars.

All cases of fractures should be sent to regular hospitals for treatment, and temporary ambulances should pass them on. You then bring into action a large number of medical bases, as well as hospitals at the front, and therefore deal with a much larger number of patients.

Colonel CRILE. **Should mobile and evacuation hospitals be grouped in threes, in fours, or should they be isolated?**

Colonel REYNOLDS. Group all hospitals where possible.

Colonel LYLE. From a transportation point of view, I agree. Group all hospitals as near together as possible.

Colonel CRILE. **Is it advisable to establish a rotation of service between the personnel of advance and rear units?**

General FINNEY. It seems to me that it would be to the mutual advantage of every one concerned—those working in the forward areas, in base areas, in intermediate areas—if each knew something at least of the problems of the others. There would then be less tendency to criticize, to feel that the other fellow who had seen the case first was not quite onto his job. I find that the more a man knows other problems the more charitably inclined he is. Therefore it is desirable that we should institute some interchange of officers from

base to front. After consultation with the administrative authorities, it was decided to change at the rate of 10 per cent a month the personnel of base and front areas. That would take about 10 months to bring about a complete change of personnel. Perhaps it would not be desirable to have a complete change; it might not be possible, but it seemed eminently desirable to have a considerable change of personnel from the front to the rear and from the rear to the front. This scheme was being worked out when the war closed. I think it has many desirable features. I think a man really can do better work at the base when he has had front line experience; nothing can bring out a man more than front line work. I feel sure that for the morale of our profession, it would be to the advantage of every one concerned to say nothing of the care of the patient. The idea was to keep a continuous circulation of personnel. Whether it would work or not I don't know; we had no opportunity to try it. I myself believe that it would have worked satisfactorily.

General Makins. I am very glad to hear General Finney raise that point. I have had large experience at base hospitals and I have always felt that it was desirable to have changes made. The most important reason is that it gives the individual medical officer a proper idea of the course of a surgical case. The majority of the men who have worked at one stage of the line have gained no experience of military surgery whatever. I have always felt that it was quite possible to have a definite arrangement by which a certain number of the men could move.

The other point that I have felt so very strongly upon is that when the men are moved they should not really interfere very seriously with the composition of the staff for the time being. The system with us was for new men who came out to be assigned to a base hospital, which served as a depot to supply medical officers at the front. I believe that is an extremely bad system, as these men interrupt the work of the hospital because they are not used to it, and in a few days they are shifted to the front.

I believe there is one method which would make a very great difference. At a base hospital, you get two classes of cases: Serious ones, and patients who stay a very short time, or slight cases. I think that all large base hospitals should be divided in two classes: (1) Serious cases, with a staff as permanent as possible. (2) Class of casualty clearing station. This is a very important point economically and medically. There is no harm in the latter hospital in changing the staff often; you can look after the patients without interfering with the work.

Economically it is a very extravagant method to pass men from base hospitals into regular hospitals. They must have everything provided for them, and some arrangement could be made by which hospitals of two classes could be a great advantage to the medical service with due economy. The idea of letting men see the progress of a case from beginning to end is very good, and it engenders confidence of one set of surgeons in the other. It is often felt that the place of a medical officer at the base is not so important as that of the medical officer at the front. This is a mistake. When a patient goes home and a verdict is passed on his case, it is never passed on the officers in the front line;

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they are scot free of criticism. If a man is supposed to have been badly treated, the medical officer at the base is criticized, not the surgeon at the front.

Colonel LYLE. There is the question of transportation. It is difficult to provide the necessary transportation.

Colonel CRILE. **What is the best method to prevent introduction of infectious diseases into first-line organizations by replacements?**

Gen. Sir JOHN ROSE BRADFORD. It seems to me that the only method of doing that is to have some organization segregated for that definite purpose. At present, all cases of infectious diseases are sent to a field ambulance.

Colonel CUMMINS. First of all one has to examine the means by which replacements are made. We have a base depot at which the troops join; from there they go to the divisional replacement battalion. We have on the other hand a corps depot through which replacements for the corps go, and in some cases a divisional unit of the same kind.

All depends on close inspection. In time of disease this would be done more carefully than usual. Certain things always escape us. It is quite certain that it is impractical to suggest swabbing of throats of the men in the depot to make sure that there are no carriers. A very important point is to have a medical officer make the inspection and pick out all men who look ill and examine them. Both at the base depot, divisional replacement units and corps replacements units, there must be a few tents put aside for the immediate isolation of any one suspicious. There must be close touch between the medical officer in charge of these units and the nearest mobile hospital.

My scheme would be to have an empty isolation hut for suspected cases, an organization to separate and observe contagious cases with good sound routine and inspections, but no elaborate system.

PROBLEMS RELATING TO THE CARE OF PATIENTS

Colonel CRILE. **Has our experience in the Argonne brought out any new points? Has anything new developed in the treatment of shock and hemorrhage?**

Lieutenant Colonel CANNON. I have had cases reported of men being brought back on stretchers with blankets over them and not under them. These men lose heat by sweat and by their wet clothing. They lose it by contact with stretchers which may be wet. It is very important to conserve the heat of the patients and see that they are properly blanketed. Report came in during the recent activity that patients in shock had four blankets over them and none under them.

I have sometimes urged that shock teams be sent to the dressing station because of the time element and low blood pressure. It is desirable that shock teams be got to work as early as possible. As a matter of fact, I think shock teams have not been working so far forward in most places.

Colonel CRILE. **What can be done for shock during the journey in the ambulance?**

General WALLACE. The heating of our ambulances is done by a system of running tube pipes under the seats and into the exhaust, but the exhaust is prevented from getting into the ambulance. It has been satisfactory on the

whole, but sometimes the ambulance gets too hot, which is bad for wounded men.

Lieutenant Colonel CANNON. We had an accident in our army which seemed to determine our action in this respect. A pipe burst, the gas leaked into the ambulance, and the patients were almost asphyxiated. We might have a pipe running from the hot-water system to the engine, when there would be no possibility of this accident occurring. Something of this sort seems desirable along with the provision of hot-water bottles in case the heating of the ambulance is not good or is lacking.

General WALLACE. We have had no question of poisoning, but I would prefer to bring the pipe underneath where the stretcher lies.

Lieutenant Colonel CANNON. Another question is as to the arrangement for caring for these patients in mobile and evacuation hospitals, and whether it is really proper to have teams constituted of medical men rather than surgeons. For future policy it seems very desirable to have some opinion on that point.

General BOWLBY. The question of warming patients comprises warm cars, warm admission rooms, and warm operating rooms. You must see that the men do not get cold in the operating theater. It is a good idea to put a small stove under each operating table so that the patient is kept thoroughly warm during the operation. Patients have often been kept warm until they got to the operating theater and not warm enough during the operation. A small stove burning under the table does a great deal to prevent patients getting chilled.

Colonel CRILE. **What during operation?**

Captain MIDDLETON. The question of warmth supplied by sand bags heated in the old-fashioned way will relieve the question of heat under the table.

The question of donors for evacuation hospitals could be solved if we could have cooperation—if one case of slightly wounded was brought in to each five or eight cases of seriously wounded. In that way the unit has a constant supply of donors.

Colonel CRILE. This is a very valuable discussion. I wish to interrupt the program for a moment and say that the A. E. F. is fortunate in having as a part of its surgical personnel Lieutenant Colonel Cannon, who has done notable work. I will call upon him to speak of his work at the laboratories at Dijon.

Lieutenant Colonel CANNON. There are certain things that have been brought out already as important matters in the treatment of shock, and which have been long recognized. Among the first is the question of heat. It has already been pointed out that a man suffering from a severe wound is likely to lose heat because of sweat and wet clothing. Another cause is low blood pressure, and there may be a reduction of 50 per cent in heat production; therefore the patient has a tendency to become cold and get into a worse condition surgically. Every effort should be made to keep up the heat of the man in all stages, from the time of wounding until recovery.

There is danger in overheating because he is likely to have lost fluids by bleeding or sweating. If you overheat him he will lose more fluid because of sweating.

In addition to the loss of body heat, and the necessity of keeping up body heat, there are several other points. A characteristic of a shocked man is that he has low blood pressure. However we may differ regarding the cause of shock, whether we regard it as primarily a matter of disturbance of the nervous system or as being caused by chemical causes, there is this consequence: The low blood pressure that prevails in the shocked man and which is likely to cause damage to the nervous system, because low pressure means slow circulation, and with slow circulation there is a lack of oxygen in the tissues, which makes them likely to suffer.

When the blood pressure is lowered by shock there is a critical level in the fall of the blood pressure, below which it becomes inadequate to keep a sufficiently rapid circulation to supply the tissues with enough oxygen to keep them normal. If this inadequate oxygen supply is allowed to continue there is damage done to the organism which gets greater as long as the condition persists. If you allow a man who is in shock or who has had a severe hemorrhage to persist in a stage of low blood pressure, he suffers damage from which it is often impossible to recover. That is the reason why the operations of the resuscitation teams should be begun as far forward as possible.

The question is asked as to what should be done during operation. If a man has suffered shock and had damage done to his central nervous system, he is extremely susceptible to ether and chloroform anesthesia. In a series of cases I worked on under General Wallace's auspices and help, we found that the average fall of blood pressure during operation was from 88 down to 62 in the course of operation. When a man has already had a low blood pressure or is suffering from low pressure, and you seriously lower the pressure still further, it is quite obvious that he is liable to undergo serious damage in consequence of that drop. If you have to use ether in these cases, a favorable condition is to make use of transfusion or other means of raising blood pressure during operation. If possible, use nitrous oxide and oxygen, which gives exactly the same degree of anesthesia without diminishing the blood pressure, but it must be used in the ratio which gives the greatest amount of oxygen. If you use too much nitrous oxide you get lowered blood pressure as with ether. The ratio should be 3 to 1.

I should say, therefore, that we have first of all:

1. Warmth as a cardinal point of treatment.
2. Prevention of prolonged persistence of pressure below a critical level.
3. Rest, both because of the effects produced on the nervous system and injury, because every movement a man makes requires oxygen, and with inadequate oxygen supply it is necessary to reduce the demand for oxygen.
4. Fluid to replace loss during shock, especially if attended by hemorrhage.

Professor Barcroft. I entirely support what Colonel Cannon has said regarding loss of oxidation in low blood pressure.

Colonel Crile. We will resume the practical side. As a basis for discussion let us say that the treatment for shock is:

1. Warmth.
2. Rest and sleep.
3. Fluids.
4. Morphia.

5. Transfusion and various methods of raising blood pressure.

Colonel CRILE. **Is morphia contraindicated in abdominal perforations? In chest?**

General WALLACE. I expressed my own opinion a long time ago. I don't think it right for any benefits to be got in the diagnosis to deny any man an adequate dose of morphia. I certainly always advocate it, and I do not think it complicates the diagnosis. Even if it takes away a man's sensibility, which I don't think it does, one has enough faith in one's self to operate if there are chances of recovery. In large doses morphia is bad.

Major CASTELLANI (Italy). I quite agree with General Wallace. Morphia is most useful.

Lieutenant Colonel YATES.—Out of 130 chest cases, I have seen two in which morphia seemed to have a bad effect, and I am inclined to think it was not due to the fact that it had been given, but because the patients had been morphinized before and no record made on their cards. Therefore, I think there is no objection to giving morphia judiciously in chest cases.

Colonel CRILE. **In battle conditions, are the tissues of the wounded desiccated? Is water of more value to the organism if it is absorbed through mucous membranes; from the subcutaneous tissues than when given intravenously? That is, should water have a biological pass?**

Professor BARCROFT. I have something to ask. In gassed patients suffering from shock we had been advised to give large quantities of hot coffee on account of the caffeine. I have wondered if it was not the water that was beneficial instead of the caffeine?

Captain ROBERTSON. I have seen men coming to a base hospital 24 hours to a week after a hemorrhage, and when we made a test of blood volume at that time we found it much reduced, even days after a primary hemorrhage, showing that circulation had not been restored. I have seen as much as 60 per cent reduction after a week. What was it due to? It is ordinarily known that after a hemorrhage the body tends to make up the loss by pouring fluid into the circulation. In these cases it had not made up the volume because the tissues had been desiccated and had no fluid in reserve. We began by giving these men large quantities of fluid—water by the mouth, and saline solution by the rectum. We gave as much as 5,000 c. c. The blood volume was quickly restored to normal. We found that these patients could take an astonishing amount of fluid by rectum. With the rise in volume there was a rise in blood pressure.

By measuring the intake of fluid and the output of urine, which normally is 3 to 2 (3 of intake to 2 of output), we found that some of these patients took very large quantities of water for relatively small quantities of urine—5,000 to 6,000 c. c. of fluid and only 600 to 700 c. c. of urine.

A case came in with a blood volume of a little over 3,000 c. c. In 20 hours the man took 5,000 c. c. of fluid and the blood volume increased to 4,700 c. c., the output of urine being only 700 c. c., showing that the fluid was taken both by the circulation and the tissues. Conditions at the battle front were favorable for a drying out of the tissues. The men in line have very little to drink; their fluid intake is very small; they work hard; they sweat a lot; and they drink

little. When they are wounded they sweat and have hemorrhage. If a man has a hemorrhage when his tissues are dried out he stands it worse than when he has had enough fluid.

General Bowlby. I think there is a great tendency to put the fluid directly in the man's veins instead of in his stomach. I have been asking lately if the man has had enough to drink. I believe that almost all these men who are admitted in a state of shock should have large quantities to drink, if they are able to drink. If they are unable to drink the next best is to give it them by the rectum. Very large quantities of fluids are absorbed by the rectum, and in many cases it does more good to give pint after pint through the rectum than 1 pint through the veins. The natural method of absorption will retain the fluids and utilize them better than if they are put into the blood, hence the necessity for giving the patient plenty to drink.

Colonel Crile. **How much injury to the donor is the taking of blood for transfusion? How many days' disability for duty should a man have?**

Captain Robertson. There is very little harm done from bleeding. The average amount of blood needed for transfusion is 500 to 600 c. c., and the average man stands that very well. If he lies down one or two hours he can go about his work without feeling any difference. The only instances when a donor is disturbed is when he has been in line three or four days with little sleep, when he has suffered from exposure, and been hungry and thirsty.

Colonel Crile. **How long may citrated blood be kept before using?**

Captain Robertson. I don't think it possible to say how long citrated blood may be kept before being used; it depends a great deal on the technic in which the blood was drawn. With good technic, very little change takes place and the blood may be kept some time, practically 24 hours, or even longer. If the inflow in the citrator has been rather slow and the transfusion not done very well, the blood will have undergone a change and you may get reaction. The aim in transfusion is to get the blood in the recipient as soon as possible. There is no objection to keeping it several hours.

In regard to the use of preserved blood for transfusion, I will say a word or two. I have kept blood as long as 25 to 26 days, and the transfusion had the same effect and was just as good as with fresh blood. In using this preserved blood there were several conditions which made the method seem quite practical. Warfare was then pretty stable, hospitals were pretty well established, and attacks were local. During such attacks large numbers of wounded came to the C. C. S., and for two or three days we would have a tremendous flood of wounded. The resuscitation ward was filled and it was impossible to give transfusion by the ordinary method. If you can store blood beforehand you can give a larger number of transfusions in the same time. Under those circumstances this method worked out very well, and we gave a great number of transfusions.

In the last three or four months our hospital became mobile and this method was not of as much use. It was too much trouble to move a large quantity of bottles, etc., and it was easier to transfuse by the usual method. If there was any difficulty in getting donors, the blood could be taken at a

central place and distributed. However, it seems more practical to regulate the donor supply.

Colonel CRILE. **Are salines as good as blood? As good as gum salt? And in what class of cases, if at all, should gum salt be used instead of blood?**

Major MIXTER. I have seen two cases in which gum salt did harm. One was a case of hemorrhage which had not been held for resuscitation at the dressing station, and while waiting for blood was given a transfusion of gum salt. The man died within half an hour. The other case was similar. These deaths were apparently caused, or at least hastened, by the gum salt.

Lieutenant Colonel WOLSEY. I have inquired of many evacuation and mobile hospitals what their opinion was of gum salt solution. In no single case did I get a favorable opinion.

X. X. Without any hesitancy I should say that gum salt solution is absolutely contraindicated. Blood pressure is increased sometimes from 60 to 130, but almost invariably it drops to 40 or 50 after a short time.

Lieutenant Colonel LEE. We have had one very excellent result from the use of gum salt; the patient was a man in a serious condition of shock after hemorrhage. The result following the introduction of gum salt was very remarkable and the man made a very nice recovery. On the other hand, two cases in a similar condition collapsed after the use of gum salt.

Captain MIDDLETON. We have had two experiences with gum salt. The results on patients received very early—3, 8, or 12 hours after being wounded—were uniformly good. In a second series of patients who were received three or four days after being wounded, the results were universally poor. The difference in results could be attributed to the difference in transportation, to exposure, and loss of body heat and fluids in the second series of cases.

At Mobile Hospital No. 1 we proceeded to give citrated blood as a uniform method of resuscitation, and our results were just as disappointing with citrated blood as with gum salt. Out of 13 cases of transfusion in three days, 8 died and only 3 showed a normal effect.

I should say that the results that have been obtained lately are due not to inferiority of methods but to the fact that you are dealing with conditions entirely different from those of summer months. In winter we are applying methods of resuscitation near the front.

Captain ROBERTSON. I was asked to look into the method of giving gum solution. I paid a visit to front-area hospitals and talked with a large number of men and got various opinions. Some of the workers were enthusiastic and had got good results, some were lukewarm, and some were against it. On looking over the records it seemed to me that the poor results reported from gum solution were largely due to the choice of unsuitable cases. There are about four classes of cases from which good results can not be expected:

1. Cases of shock for a long period—15 to 20 hours or more—with so much damage done the tissues and brain cells that blood pressure is very low and transfusion has no effect.

2. Cases treated immediately by gum salt; patients brought into the resuscitation ward and not given time to pick up with heat, morphia, and fluids. These do badly.

3. Cases suffering from very severe blood loss. Gum salt solution gives a temporary rise in pressure, but they have too little oxygen and the pressure is not maintained.

4. Gas bacillus cases. We made a post-mortem of cases that did not do well after gum injection, and in every case we found gas bacillus.

Where these various considerations are taken into account and gum solution used on that basis, results are good.

Sir WALTER FLETCHER. It is a matter of great importance that the experience of the past months should be placed on record; I hope records have been collected. It is very important to have the clinical condition of the patients, the method of making the solution, and the method used for transfusion. There is certainly a wide variation in the quality used in France. In Italy experiences have been uniformly unfavorable because the solutions used were unsuitably prepared. Improvement in the solution changed the experience. altogether.

Last week we received reports from Macedonia; the experience was bad, and it is clear that they had been using solution in the same form as in Italy.

Alkaline solution of gum is very difficult to prepare; great attention should be paid to filtering.

The point is not clear whether gum solution should be used; we have not yet received reports with enough detail to see if it should be used or not.

General FINNEY. In going round various hospitals I was struck with one point. In several of the hospitals I was told that the solution from the central laboratory was not giving satisfactory results. Solution made fresh in the hospitals gave good results. This happened in several hospitals. The reason for the unsatisfactory results was the question of time; fresh solution gave good results.

Lieutenant Colonel CANNON. There is evidence on both points that Sir Walter Fletcher has brought up. The first one was the clinical condition of the patient at the time the solution was used. I have had experience under two conditions. When the patient was received early, the result was good. When the patient was received late the result was unfavorable. In one sector of the British Army last spring in an advanced station excellent results were obtained from gum solution. Eighteen miles behind the front, with the same method, unfavorable results were obtained. So the clinical condition of the patient is one that will very largely determine the value of the method. I have a letter from one of the resuscitation officers who reports that in transfusion of blood he got chills in cases of low blood pressure from shock.

There are differences in the gum used. The gum which has been used in the British Army was provided in clear lumps. In France, we had to get powdered gum and we found that it contained starch and * * * I have removed 60 per cent blood volume from an animal and given it gum salt solution; the animal recovered. So both conditions mentioned are important.

From the very beginning I have urged that this solution be used as far forward as possible. Farther back I have found that in mobile units gum salt solution has been used instead of blood, because of the lack of donors, with bad results.

If an organism has been suffering from low blood pressure for some length of time, it makes no difference whether you introduce blood or gum, you get unsatisfactory results. I would emphasize that it is the first essential to have these resuscitation measures applied as soon as possible, before damage due to low blood pressure has come to a point from which the patient can not recover. I would like to know whether persons who have used salt solution and think favorably of it have made blood-pressure observations to prove that it does any good whatever. I believe that if you introduce salt solution you get a rise in the pressure, but I do not believe that it is permanent. Gum salt remains in the blood vessels and salt does not.

Last Friday, at a meeting in Boulogne of men who had had experience in the British Army, the following statement was approved by the committee.

"1. Provided that the gum solution is prepared from good gum, with a raised body temperature, and slowly injected, no seriously harmful results need be apprehended in its use.

2. The amount injected should be 700 c. c."

Colonel Crile. **In emergencies, may grouping be disregarded?**

Does any one object to answering "Yes"?

Colonel Crile. **In the anemia by a tourniquet, are damaging chemical compounds formed?**

Lieutenant-Colonel Cannon. Shock can be produced by shutting off the blood circulation for a time. We have had a number of cases of men who have had a tourniquet on for some time after being wounded and who have gone in shock on removal.

Colonel Crile. **Is the blood of a gassed case as useful in transfusion as the blood from a normal one?**

X. X. (French). In the French Army we use the blood of gassed cases for transfusion. What could oblige us to refuse transfusion from a gassed case? We may be sure, from experience, that there is no poison in the blood. Of course one will not use as a donor a man who is in an acute stage of gas poisoning, but I don't see why we should not take blood for the making of citrated blood from slight cases. There are many men in favor of keeping this blood, because it seems to be the best blood for transfusion, because it is concentrated with a high percentage of red cells, and is very apt to take up oxygen.

Lieutenant Colonel Cannon. I made use of blood from slightly gassed cases in July last, and called attention to the availability of these men as donors. There is no harmful effect but definite value to be got from this blood.

Colonel Crile. **What is the anesthetic of choice? What is the field of local anesthesia? Of spinal?**

Lieutenant Colonel Clinton. The American Army is obliged to use ether almost universally. A few operators have facilities for using nitrous oxide, but the standard has been ether through necessity. Nitrous oxide is preferred if available.

General Wallace. We have found gas and oxygen by far the best anesthetic in cases of shock. The worse a patient is, the easier it is to operate him by gas and oxygen, and it is the safest to give him. Apart from that, the usual anesthetic in the British Army is warm ether. We have avoided chloro-

form as a general anesthetic except for the purpose of conduction; still for a limited number of mouth and chest cases it can be used combined with oxygen.

Spinal anesthesia has not been much used; it is not advisable to use it if one is not thoroughly educated in its use.

Local anesthesia has been used in conjunction with gas and oxygen in particular cases; it is very useful in abdominal cases; it has been used by those who have been skilled in its use, and good results have been obtained. Generally local anesthesia takes too long to act.

We feel under a great debt of obligation to the American Army for their skilled anesthetists, especially in gas and oxygen. Gas and oxygen, as it has been given by skilled people, has saved many lives of patients under shock.

Colonel Crile asked General Makins to comment on the influence of war surgery on the surgeon when he returns to civilian practice.

General Makins. **What effect will military surgery have upon civilian work at home?** It can not be thought that it will have any marked influence on surgery at home. In civil life we should always open an abdomen, and in certain cases get successful results as in the Army. It is only in this war that facilities have been provided for taking the cases early enough. One thing in civil surgery which has been developed is surgery of the chest. When we come to surgery of the lung I think there is no doubt that there will be more of that; still, those who have only gained experience in military surgery will find lung surgery very different in civil life. As to the question of the development of the surgeon, it is quite clear that the work of a military surgeon must develop many qualities in a man; it develops quickness in making up one's mind, resourcefulness in meeting many great difficulties, etc. There is, however, one side where military surgery is not good as an example for the civilian surgeon; the personal responsibility is much greater in civil life. Younger men will have to bear that in mind when they go home and operate.

Colonel Crile. The program is now completed and there remain for me two pleasant duties to perform. The first is to express, though inadequately, our appreciation of the part taken in this meeting by our British, French, and Italian colleagues, who have given freely of their wider experience in elucidating our problems.

My second duty is to say something on our own behalf. I have had opportunity in the course of my duties to see the work at many mobile, evacuation, and base hospitals. In our first offensives, through lack of experience in military surgery on the part of some of our surgeons in certain instances, the work showed deficiency, but in the last offensive the work was uniformly of a high order. In view of the progress made during our brief experience, I feel that we have reason to be highly gratified with the results secured.

AT THE BASE

The Research Committee of the American Red Cross in France, desiring a record of the experiences of the surgeons of hospitals in the American Expeditionary Forces, concluded to devote one session of the Research Society of the American Red Cross to a conference on surgery at the base. Accordingly a questionnaire was prepared by Brig. Gen. J. M. F. Finney, M. D., and Col.

George W. Crile, M. C., to be sent to the various base hospitals for replies for use as a basis for discussion. The questionnaire was quite comprehensive in that it dealt with a number of phases of some of the most important hospital problems, particularly those relating to war wounds.

The questionnaire was sent to commanding officers of base hospitals for opinions based on the clinical experience of the surgical staffs. Many replies were received, and the discussions on a number of problems, although necessarily brief, are a distinct contribution to the surgical literature of the war. Prior to the receipt of the responses, however, meetings of the research society had been discontinued. The responses, therefore, were summarized in the nature of a consensus of opinion, and published to the medical officers of the American Expeditionary Forces by the research society.

Though the queries were propounded for surgeons at the base, their pertinence was in the majority of instances to surgery at the front; it is deemed desirable, therefore, to include the summary of responses to them in the present chapter.

RESPONSES TO QUESTIONNAIRE ON "SURGERY AT THE BASE"

* * * * * * * * *

Q. 4. **How long should abdominal cases be held at the front before transportation?**

A. Consensus: Until danger from acute peritonitis is past—from ten days to two weeks, depending upon nature of wound and operation procedure.

Q. 5. **How do through-and-through chests travel?**

A. Number of votes: Badly, 8; well, 23.

Expression of remainder:

1. Well after one week.
2. Shrapnel, poorly—perforating rifle bullet wounds, well.
3. Nonoperated cases without shock, well.
4. Operated cases before healing or those with severe intrathoracic conditions, badly.

Remark: Difference of opinion evidently accounted for by results due to factors of transportation and sector conditions.

Q. 6. **What type of cases are most injured by travel?**

A. (*a*) Penetrating abdominal.

(*b*) Muscle wounds in locations favoring developing of gas infection—buttocks, etc.

(*c*) Compound comminuted fractures of femur, with or without knee-joint involvement.

(*d*) Severely shocked cases.

(*e*) Brain cases.

(*f*) Sucking chest wounds.

(*g*) Complicating pneumonias.

(*h*) Fresh amputations.

(*i*) All improperly splinted fractures.

(*j*) High-explosive chest injuries.

(*k*) Operated abdominal wounds.
(*l*) All serious injuries with acute infections.
(*m*) Wounds involving large vessels.
(*n*) Recent hemorrhage.
(*o*) Gassed cases.
(*p*) Fractured spines.
(*q*) All bad joint injuries.

Q. 7. **What is the comparative condition of wounds arriving at the base dressed with:**
(*a*) Dry gauze.
(*b*) Dichloramine-T.
(*c*) A protective.
(*d*) Rubber tubes.
(*e*) Carrel-Dakin.
(*f*) Vaseline gauze.
(*g*) Bipp.
(*h*) Flavine.

A. Votes expressing best results: Dry gauze, 13; Carrel-Dakin, 12; vaseline gauze, 5; flavine, 3; dichloramine-T, 1; rubber tube, 1; protective, 1; Bipp, 0.

Remark: Nearly all observers emphasize the risk of packing the wound *tightly* with any dressing—lightly placed surface dressings necessary.

A thorough primary operation procedure associated with proper splinting much more important than any type of dressing used.

II. Gas Gangrene

Q. 1. **To what extent, if at all, do the following predispose to gas gangrene?**
(*a*) Ligation of main artery of a limb.
(*b*) Tight bandages.
(*c*) Tight packing of a wound.
(*d*) Insufficient débridement.
(*e*) Low vitality from shock and hemorrhage.

A. General concensus that all factors mentioned predispose as follows:
(*d*) First cause.
(*a*) Second cause.
(*b–c*) Third cause.
(*e*) Fourth cause.

Q. 2. **What is the indication for local operation? For amputation?**

A. Agreement that essential indication for local operation is: Involvement of definite muscle or small muscle group which can be completely removed without loss of function of limb. For amputation—evidence of massive gangrene of limb; where removal of involved tissue can not be acomplished without destruction of function of limb; when complicated by serious injury to main arteries of limb; when extensive fracture of large bones and joints co-exists; in doubtful cases in which patient suffers from extreme shock and hemorrhage; and where there are other wounds requiring operation in which there is general constitutional evidence of a severe fulminating type of infection.

Q. 3. **What is the value of antigas sera?**

A. Base Hospital No. 19: 15 cases with sera treatment previous to admittance; 4 of these developed gas infection, 2 died, and 2 recovered, the 2 dying requiring additional operation after admittance.

Base Hospital No. 48: Enthusiastic over serum as prophylactic—Bull's serum, 40 c. c. intravenous, repeated in 30 c. c. dose, with rising pulse, the open wound being washed with hydrogen peroxide.

One response: "Nil."

Base Hospital No. 6: "Favors for both prophylaxis and early treatment."

A. R. C. Military No. 2: Experience limited. In few cases used—not encouraging. Trouble to get best anerobic sera. Experimental evidence good, and practical tests show no prophylactic or therapeutic value of the gas bacillus antitoxin; other anerobic antisera in hands of certain French physicians show evidence of possible value.

Q. 4. **Is it justifiable to base local operation or amputation on the bacteriological findings alone?**

A. "No" sums up answer to this question.

Q. 5. **Is the general range of temperature high or low? Pulse rate high or low?**

A. General agreement that pulse runs high and temperature comparatively low—pulse from 110–130 with temperature 101–102° F. in average cases.

Q. 6. **How frequently does gas gangrene attack tissues other than muscle?**

A. Responses:

(*a*) Secondary involvement of subcutaneous tissue.

(*b*) Chest involvement not uncommon.

(*c*) Often begins in ecchymoses of fascia and in blood clots.

(*d*) In many autopsies gas found in liver.

Remark: All other reports agree that tissue other than muscle is rarely affected. The above remarks are additional statements from four hospitals.

III. Débridement

Q. 1. **What is included in a good débridement?**

A. Consensus:

(*a*) Sparing removal of skin about wound margin.

(*b*) Any necessary enlargement of wound and proper retraction.

(*c*) Removal by sharp dissection of all contaminated, contused, devitalized tissue lining wall of tract of missile, with avoidance of injury of any important blood vessels and nerves.

(*d*) Removal of foreign bodies including pieces of clothing.

(*e*) Scrupulous hemostasis and drying by ether lavage (optional).

(*f*) Fixation of remaining organisms by tincture of iodine (optional, but believed by some to be of value).

(*g*) Especial care with regard to muscle tissue removed, with contraction, bleeding, and normal muscle color, the guides in reaching normal muscle tissue.

(*h*) Guarded removal of unattached bone fragments.

(*i*) Direct observation, by good headlight, of wound tract.

Base Hospital No. 48 emphasizes great importance of transfixion suture (pig's-gate) in depths of posterior-tibial or similar wounds, believing it to save much secondary hemorrhage and many lives.

Q. 2. **What errors in débridement have you noted?**

A. Consensus:

(*a*) Inadequate exposure of wound tract.

(*b*) Incomplete removal of damaged and contaminated tissue.

(*c*) Unnecessary transverse section of muscle.

(*d*) Undue sacrifice of skin (important).

(*e*) Too firm packing with gauze and through-and-through drainage.

(*f*) Unnecessary damage to important vessels and nerves.

(*g*) Short cuts to foreign bodies without following wound tract.

IV. Tetanus

Q. 1. **How many cases?**

A. Cases seen, 91; to total admissions, 0.018 per cent.

Q. 2. **Results?**

A. 37 deaths; rate, 61.66 per cent.

Note.—Death percentage based on 60 cases with complete data. Thirty-one cases from one hospital not giving deaths not included in this percentage.

Q. 3. **Are there any contraindications to giving a second dose of antiserum?**

A. Opinions:

(*a*) Anaphylactic reaction following first dose.

(*b*) If an anaphylactic individual is properly desensitized, no objection.

(*c*) Unwise if full dose has been given and patient is profoundly septic.

(*d*) No; if given before 10 days.

(*e*) Yes; severe and dangerous primary reaction.

Remark: With exception of above opinions, all observers agreed that there was no objection to a second dose.

Q. 4. **Have you seen local tetanus?**

A. Votes: Yes, 7; no, 27.

Q. 5. **Discuss late tetanus—cause—prevention.**

A. Expressions of cause:

(*a*) Reopening of old wound in operation around rectum.

(*b*) Mechanical trauma—operative or other.

(*c*) Insufficient primary operation; secondary operation; insufficient drainage; improper dressing; insufficient serum.

Prevention: Correction of above and always giving serum before secondary operation.

Remark: Most hospitals stated that they had seen little or no late tetanus.

V. Delayed Primary Closure

Q. **Bacteriological control or clinical judgment?**

A. Votes: Bacteriological control, 5 (Base 6 laboratory has once given 168 reports in 48 hours); clinical judgment, 10; both when possible, all.

Q. (2) **Average time after primary operation?** (3) **Percentage of successes?** (4) **Has there been loss of life or limb following failures?**

A.

2	3	4
Days	*Per cent*	
10–12	98	[1] 1
10	65	0
([2])	94	0
3	[3] 95	0
2–5	----------	0
3–4	80	[4] 2
3	95	0
10	75	0
10	85.9	0
3–5	90	0
4–7	90	0
10	95	0
6	65	0
2–4	70	0
8	75	[5] 1

[1] Death tetanus.
[2] Undetermined.
[3] About.
[4] Deaths gas infection.
[5] Limb.

Remark: It is noted that the first hospital, Base No. 6, relied, with special care, on bacteriological findings by culture methods.

VI. Preoperative Cases

Q. 1. **What types of case need no operation?**

A. (*a*) Perforating bullet wounds (including machine-gun and rifle) of soft parts, *exclusive* of belly wounds, with no marked hematoma or other evidence of marked injury to important vessels, and with no evidence of serious nerve lesions; with small wound of entrance and exit, and without marked bone injury, provided there is no obvious infection present.

(*b*) Minute foreign bodies in small penetrating wounds.

(*c*) Nonsucking wounds (penetrating and perforating chest) without symptoms; or early cases of the same type without serious internal or external hemorrhage.

(*d*) Certain head cases—extreme care in determining.

Q. 2. **How have cases evacuated without operation (preoperative) done?**

A. Ten reports; no experiences.

Well

(*a*) If within 24 hours; wounds of buttocks.
(*b*) Perforating, except belly and head.
(*c*) Slight superficial.
(*d*) All.
(*e*) All.
(*f*) All.
(*g*) All.
(*h*) Superficial.
(*i*) All.
(*j*) All.
(*k*) Except tarsal involvement.
(*l*) All.
(*m*) All simple perforated of chest and soft parts.
(*n*) Majority.
(*o*) All except calf, buttock, thigh, thorax, and subscapular.
(*p*) All.

Badly

(*a*) Majority infected.
(*b*) All serious wounds.
(*c*) None as well as operated cases.
(*d*) Infection except in perforating wounds.
(*e*) All.
(*f*) 95 per cent badly.
(*g*) All.
(*h*) Higher mortality.
(*i*) All except simple perforating of soft parts and chest.

Q. 3. **List the types of cases suitable for evacuation without operation.**

A. See heading No. 1. Many wounds of hands and feet, a few spine, and some head cases.

Q. 4. **What are the advantages and the disadvantages of the preoperative train?**

A. Ten reports; no experience.

All others agree that properly scheduled trains clear front area hospitals, in time of stress, of cases in which operation can be delayed without danger to life or limb or function.

VII. Chest Surgery

Q. 1. **What are the indications for operation in the front area?**

A. (*a*) Sucking chest wounds.

(*b*) Serious hemorrhage.

(*c*) Large effusions.

(*d*) Driven-in bone fragments.

(*e*) Large foreign bodies.

(*f*) Collapsed lung—same side as wound.

(*g*) Much rib comminution.

(*h*) Infection.

(*i*) Hemothorax with tension.

(*j*) Pneumothorax with tension.

(*k*) Foreign body in heart or pericardium.

(*l*) Foreign body in mediastinum.

(*m*) Simultaneous wounds—both sides of chest.

(*n*) Hemothorax plus anerobic infection.

Q. 2. **What are the indications for operation in the base?**

A. (*a*) Empyema.

(*b*) Lung abscess.

(*c*) Secondary hemorrhage.

(*d*) Sinuses due to foreign bodies.

(*e*) Pus pockets.

(*f*) Hemothorax with symptoms. (Repeated aspirations when necessary.)

(*g*) Radical thoracotomy for infected hemothorax.

Q. 3. **Discuss the anesthesia—the operation technic.**

A. Anesthesia. Local, if possible, recommended by all.

Stated first choice: Gas oxygen, 18; ether, 9; chloroform, 2; with morphine and atropine, 3; warm ether, 1.

Operative technic. Definite opinions: For hemorrhage and removal foreign bodies, 6-inch incision, 5-inch of fourth rib removed. Begin incision at costal cartilage. Rib spreading. Split fibers pectoralis major. Lung delivered through wound. Palpation. Incision into lung to deliver f. b. Lung sutured by fine catgut. Hot sponge for oozing. Fine catgut for other bleeding. Gentle sponging of blood from chest cavity. Parietal pleura closed by continuous fine suture—catgut. Muscle and skin sutured to make air-tight. All these chest wounds to be closed primarily.

Fluoroscopic table often used.

Always practice principle of thorough débridement and following of tract whenever possible in primary removal of foreign bodies—with radioscopic assistance.

Septic cases—thoracotomy; suction drainage, positive pressure by blow bottles as soon as possible

Q. 4. **Discuss the aftertreatment.**

A. (*a*) Sitting posture.

(*b*) Morphine as indicated.

(*c*) Aspirations of effusions after 48 hours for drainage and displacements.

(*d*) Prompt radical drainage for infections (optional carreling of pleura when no open bronchus).

(*e*) Cases should not be evacuated.

(*f*) Rest essential.

(*g*) Lungs expanded regularly as soon as condition permits. (James' bottle method satisfactory).

(*h*) Warm and dry climate afterwards, if possible.

Remark: Eight expressions, only, in favor of Carrel-Dakin or other irrigation in infected chests. With these exceptions, general agreement in above principles.

VIII. Secondary Hemorrhage

Q. 1. **In what type of case does it usually occur?**

A. Most commonly in extremities.

Consensus:

(*a*) Infected wounds with or without primary injury to vessels; usually primary injuries.

(*b*) Infection after extensive débridement in presence of foreign bodies.

(*c*) Prolonged use of drainage tubes.

(*d*) Compound fractures with gas infection.

(*e*) Following amputations.

Base Hospital No. 2, B. E. F. Series of 46 cases:

(*a*) Comminuted fractures, tibias and fibulas, 17 per cent.

(*b*) Fractures of humerus, 13 per cent.

(*c*) Wounds of thigh, without fracture, 13 per cent.

(*d*) Buttock wounds, 11 per cent.

(*e*) Wounds popliteal region, 11 per cent.

Q. 2. **Should first indication be ligation or temporizing?**

A. Stated preference. For ligation, 24; for temporizing, 3.

A. R. C. Military Hospital No. 2: "Ligation, if can be done in wound. Hesitate before ligating an arterial trunk to stop hemorrhage in an infected wound. Amputation often preferable, especially when complicated by gas."

Q. 3. **What are the predisposing causes of secondary hemorrhage?**

A. (*a*) Improper hemostasis.

(*b*) Early transportation of amputations and hemophilics.

(*c*) Faulty débridement.

(*d*) Insufficient drainage.

(*e*) Excessive restlessness.

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(*f*) Traumatic aneurism.

(*g*) Rubber tubes in proximity to vessels.

(*h*) Faulty ligatures.

Remark: One definite expression that Carrel-Dakin solution favors hemorrhage, by dissolving ligatures and loosening blood clots.

Q. 4. **What is the general treatment?**

A. General agreement:

(*a*) Transfusion of blood after control of hemorrhage.

(*b*) Fluids by mouth and rectum or subcutaneously, forced.

(*c*) Absolute quiet.

(*d*) All general treatment of shock.

(*e*) Intravenous saline inferior to transfusion.

IX. Knee-joints

Q. 1. **In through-and-through machine gun or rifle wounds, how do nonoperative compare with operative results?**

A. Definite opinions: Nonoperated cases—"Do as well as," 9; "Not so well," 4; "Do better," 17. Most qualify by remark, "Unless extensive bone injury."

Q. 2. **In débridement do you advise—**

(*a*) Complete closure?

(*b*) Closure of capsule and fascia?

(*c*) Leaving the wound entirely open?

A. Votes: (*a*), 15; (*b*), 20; (*c*), 1. Seton drainage to capsule recommended by 2.

Q. 3. **Is shattering the head of the tibia or of the condyles of the femur the more serious?**

A. Votes: Head of tibia, 17; equally serious, 4; condyles, 10.

Base Hospital No. 2, B. E. F.:" Injured condyles with joint-involvement, 40; infected, 19; amputations, 18; head tibia with joint-involvement, 15; infected, 7; amputations, 5."

Q. 4. **What type of knee injury demands immediate amputation?**

A. Consensus:

(*a*) Extensive destruction both bones beyond limits of functional recovery, with associated injury to main vessels.

(*b*) Extreme destruction with fulminating infection.

(*c*) With extensive comminution of lower third of femur or upper third of both bones of leg, or when popliteal artery is severed.

Q. 5. **What type of infection and what extent of involvement of the joint demands amputation?**

A. Consensus: Streptococcus infection of fulminating type with severe systemic symptoms, progressive, especially when associated with much bone injury, or when infection extends to muscle planes, or when burrowing abscesses form. The gas bacillus and staphylococcus not as frequent agents as the streptococcus in necessitating amputations.

Base Hospital No. 2, B. E. F.: "In general, panarthritis demands amputation, though resection is sometimes possible in specially favorable cases."

Their figures are:

	Cases	Amputations
Streptococcus	11	9
Staphylococcus	6	3
B. welchii	7	5

Q. 6. **In knee-joint injury and infection, has more error been made in conserving or in amputating?**

A. Votes: Conserving, 21; amputating, 5.

Remark: One expression that error has been in amputating too frequently at the front and conserving too much at base.

Q. 7. **What effect has excision of the patella on the function of the joint?**

A. Most observers agree that excision results in marked interference with function, the joint being weakened to such an extent that mechanical apparatus is necessary; that the patellar ligament serves, with difficulty, the function of extension unless the knee is thrown in backward curve. Stiff joint also stated to occur.

Definitive votes: Good function, 3; poor function, 9; little effect, 3.

Q. 8. **Compare mobilization with immobilization in the treatment of joints (Willem's method).**

A. Votes: For immobilization, 6; for mobilization, 16; remainder either no expression or misinterpreted question.

Q. 9. **What is your estimate of the value of antiseptic treatment of knee-joints?**

A. Votes: Desirable, 7 (Carrel-Dakin used by these); undesirable, 25.

X. Antiseptics

Q. 1. **Compare the principle of chemical antiseptics with the principle of nonchemical treatment of infected wounds.**

A. Treatment by chemical antiseptics preferred by 28; nonchemical treatment preferred by 7.

Remark: Carrel-Dakin method choice among those using antiseptics.

Q. 2. **List antiseptics in order of their availability for battle conditions at the front areas—at the base.**

A. Availability order:

At front	*At base*
Iodine.	Carrel-Dakin.
Carrel-Dakin.	Alcohol.
Alcohol.	Iodine.
Flavine.	Dichloramine-T.
Mercury Salts.	Mercury Salts.
Ether.	Boric Acid.
Dichloramine-T.	Ether.
Lysol.	Picric Acid.
Phenol.	Lysol.
Bipp.	Bipp.
Acetic Acid.	Acetic Acid.
Balsam Peru and Castor Oil.	Burrow's Solution.
	Iodoform.

XI. Anesthetics

Q. 1. **How do you value the nurse anesthetist?**

A. Votes: Very satisfactory, 25; satisfactory, 8; unsatisfactory, 1 (for prolonged operations); corps men, 1; none used, 1.

Q. 2. **In what cases and under what circumstances may local anesthesia be used? Regional? Spinal?**

A. Definite opinions:

Local

1. Selected head cases.
2. Thoracotomy.
3. Dental surgery.
4. Small surface operations with superficial foreign bodies.
5. Face operations.
6. Secondary closures.
7. All chest where general anesthetic contraindicated.
8. Selected abdominal cases.
9. Majority spinal cases.
10. Drainage of abdomen if general anesthetic contraindicated.
11. Many brain cases.
12. Superficial abscesses.

Regional

1. Maxillofacial surgery often.
2. Operations in orbit and about orbit.
3. Certain cases of skin-graft.
4. Certain spinal cases.
5. In clean surface operations, too extensive for simple local anesthetic, where general is contraindicated.

Spinal

1. Certain shock cases, combined with gas oxygen or with morphine plus hyoscin.
2. Crushed legs plus bladder injury, if not too low blood-pressure.
3. Amputations of lower extremities in desperate cases.
4. Perineal wounds where general anesthetic contraindicated.

Q. 3. **In what cases is gas and oxygen especially indicated?**

A. Consensus:

(*a*) Chest cases frequently. (With acute bronchitis.)

(*b*) With tuberculosis (pulmonary). (With gas complication.) (With influenza.)

(*c*) Short débridement.

(*d*) All cases except brain and abdominal, especially chest and shock.

(*e*) Septic.

(*f*) All lung operations.

One expression that ether is preferred in all cases.

Q. 4. **Has the type of anesthetic influenced results?**

A. Votes: Yes, 30; no, 3: One states "Not as important as anesthetist."

Q. 5. **How do you value Depage anesthesia?**

A. 17 hospitals report "No experience"; 7 hospitals report "Highly valued"; 2 hospitals condemn; 1 hospital "No better than ethyl-chloride." Base Hospital No. 22, in 50 cases use very satisfactory. Base Hospital No. 60, most practical general anesthetic for front area; quick narcosis and recovery; easily transported; used in over 200 cases.

XII. Fluids

Q. 1. **Compare sodium bicarbonate with normal saline in treatment of shock and hemorrhage.**

A. Votes: Normal saline superior, 11; sodium bicarbonate superior, 4; no difference, 10; no opinion, 8; both nonessential, 2.

Q. 2. **Compare intravenous saline infusions with giving water by mouth or rectum, or subcutaneously.**

A. Consensus: That whenever possible water should be given by mouth and rectum, as by the mucous membrane it is almost entirely absorbed, though comparatively slowly. A few prefer intravenous under all conditions, but most state a preference for its use when quick action only is desired after acute hemorrhage, or in shock, using subcutaneous method when less haste is desired.

Q. 3. **Compare gum-salt with saline; with blood.**

A. Votes:

First place: Blood, 31; gum-salt, 0; saline, 0.

Second place: Blood, 0; gum-salt, 13; saline, 10.

Third place: Blood, 0; gum-salt, 9; saline, 10.

Q. 4. **Have you noted any ill effects from gum-salt?**

A. Votes: Yes, 13; no, 11.

Base Hospital No. 20. Unfavorable reaction in 15 per cent of the cases. Three deaths attributed to solution.

Base Hospital No. 6. Nothing to recommend it.

Base Hospital No. 19. Two cases.

Base Hospital No. 15. Considered dangerous.

Base Hospital No. 48. Several deaths attributed to its use. Very positive against its use.

XIII. Blood Transfusion

Q. 1. **What method preferred?**

A. Votes: Sodium citrate, 26; whole blood with paraffin tube, 3; Kimpton-Brown method, 1; syringe method, 1.

Additional Expressions: Three votes for citrate in front area. Indirect tube method for base, 1 vote. One states paraffin tubes and citrate equally successful.

Q. 2. **Have there been any serum reactions when properly grouped?**

A. Votes: No, 29; yes, 0; slight and rare, 5.

Q. 3. **What results in prolonged infections?**

A. Ten hospitals report "No improvement;" 14 hospitals report "Definite improvement"; 2 hospitals report "Temporary improvement;" 7 hospitals report "No experience."

Q. 4. **Discuss available sources, difficulties encountered, etc.**

A. Sources: (*a*) Corps men; (*b*) prisoners (carefully selected); (*c*) slightly gassed and wounded, very carefully selected. Difficulties: (*a*) Length of time necessary to collect from donors; (*b*) clotting in needle when injecting blood; (*c*) inability to secure suitable donors; (*d*) corps men off full duty from 24-48 hours after donation; (*e*) keeping donors under careful control.

XIV. Amputations

Q. 1. **What is the value of the guillotine operation?**

A. Votes: Favorable, 19; unfavorable, 7; no advantage, 3; speed only, 7. Reasons for favorable votes: Rapidity, drainage, little shock.

Q. 2. **Is the mediotarsal amputation justifiable?**

A. Yes, 11; no, 18; no observation, 2; noncommittal, 3.

Q. 3. **Compare the Symes's and the lower third amputation.**

A. Votes: For Symes's, 5; for lower third, 24; remainder either no experience or no preference.

Q. 4. **Is the rule that stumps of the lower extremities shall have no terminal scar a good one? On the upper extremities is the terminal scar always correct?**

A. Votes: (*a*) Yes, 15; no, 8. (*b*) Yes, 11; no, 8.

Q. 5. **Are amputations through the knee-joint recommended?**

A. (*a*) Yes, in emergency, 6. (*b*) No, 28.

Q. 6. **Shall the bones of the stumps be left with parallel or conical shape?**

A. Votes: Parallel, 13; conical, 8.

Q. 7. **How near the knee-joint may amputations be made?**

8. **How near the elbow-joint?**

9. **Through the elbow-joint?**

A. Consensus: In knee-joints a margin of from 3 to 5 inches above, and about 4 inches or through tuberosities below, is the margin to be allowed; and just below the bicipital tuberosity and just above the condyles of the humerus is the margin for vicinity of elbow-joint. Amputations through the elbow-joint advised by only two.

XV. Head Injuries

Q. 1. **Should all lacerations of the scalp be explored surgically for fracture even if fluoroscopic report is negative?**

A. Votes: Yes, 31; no, 3.

Q. 2. **Discuss foreign bodies in the brain.**

A. Consensus: (*a*) Accurate localization. (*b*) Whenever accessible, foreign bodies should be removed unless multiple and minute, and through the tract of entrance, care being used to avoid further brain injury. Prolonged search with instruments or finger contraindicated. Thorough cleansing of tract of softened tissue, bony fragments, dirt, etc., by catheter suction (gentle) and irrigation, then soft catheter as searcher. Foreign bodies in brain, with clean tract, not always a menace, and careful judgment should be exercised in their removal. Considered more important to clean the tract well than to remove foreign body, as abscess formation more frequent in tract than about foreign body.

Q. 3. **Is the magnet useful in extracting large foreign bodies?**

A. Votes: Yes, 12; no, 4.

Q. 4. **Have you seen late abscesses?**

A. Votes: Yes, 25; no, 4.

XVI. Hospital Problems

Q. 1. **What improvement can you suggest in the arrangement of the standard American base hospitals?**

A. Remark: Few opinions of definite nature. Buildings more concentrated, especially surgical wards and X-ray room and laboratory; these preferably connected by corridors; special quarters for sick nurses; more liberal quarters for corps men—at present badly crowded; 1,000 capacity instead of 500 would be more easily expanded; better facilities for heating receiving ward;

larger and better equipped kitchens; better facilities for hot water; usually impractical to have special hospitals, but special services in base centers should be arranged when distribution of cases is possible, with well-balanced staff to serve them.

Personnel: Two hundred and fifty corps men, at least; Sanitary Corps should handle all mess, quartermaster, and supply problems; more permanent personnel, as constantly changing personnel interferes badly; more care in detaching personnel, thus preventing crippling of heavy services; competent permanent skeleton staff, with chief and assistant for each service.

Q. 2. **What are the advantages and limitations of the surgical team?**

A. Advantages: (*a*) Marked: "Rank should not remove experienced surgeon from the wounded soldier."

(*b*) Elastic and mobile service for reinforcement.

(*c*) Complete independent mobile unit.

Limitations: (*a*) Too small.

(*b*) Should be organized always according to surgical ability and not rank.

Q. 3. **What should be the size of a mobile hospital?**

A. (*a*) About 200 beds with accessory hospitalization equipment.

(*b*) 300–600 beds: in Bessonneaux—10 teams, 5 day, 5 night; 150 200 major operations in 24 hours.

Remark: Few answers—most stated no opinion.

Q. 4. **What should be the equipment of a mobile hospital?**

A. (*a*) Such as to enable it to operate independently.

(*b*) About same as French auto-chir; with American instruments and X-ray apparatus.

Remark: Few answers and no statements of complete equipment.

Q. 5. **What should be the function of mobile hospitals?**

A. Consensus:

(*a*) Must be very mobile to serve any other purpose than the usual evacuation hospital serves.

(*b*) Must advance with army to handle all urgent cases, and evacuate as early as possible Located as near front lines as particular sector conditions permit.

Q. 6. **Is it best to have special hospitals, such as head, chests, fractures, or to have special wards for such cases in general hospitals?**

A. Votes: For general hospitals, 30; for special hospitals, 5.

Q. 7. **What suggestions as to—**

(1) Surgical instruments. (*a*) Quality. (*b*) Types. (*c*) Quantity.

(2) Dressings.

(3) Special types.

(4) Bandages. (*a*) Special. (*b*) Splints.

A. Consensus:

(1) (*a*) Quality, in general, should be higher.

(*b*) Many missing types for special work.

(*c*) Quantity recorded as sufficient in about one-half of the responses.

(2) (3) (4) Dressings, bandages, and splints abundant and satisfactory.

CHAPTER VI

ANESTHESIA

The problems presented by the wounded in their relation to anesthesia may be grouped (1) according to the general condition of the soldier and the length of time between the receipt of his injury and operation; or (2) according to the type of wound and the part of the body injured. Thus, in the front line hospitals men still suffering from shock or hemorrhage might require an immediate operation, and even the lightly wounded, on account of exposure, fatigue, cold, possibly lung involvements, bronchitis in particular, would be but little able to endure well the dangers of an inhalation anesthetic. Under each of these varying conditions—at the front-line station, the lightly wounded but exhausted soldier and the seriously wounded soldier in shock; and at the base hospital, the soldier who has arrived hours or days after his injury was received in whom infection has mounted and even gas gangrene may have developed—what is the anesthetic method of choice, and does the part involved also influence the choice of the anesthetic?

During the World War the choice of anesthesia lay among chloroform and ether and nitrous oxide-oxygen as general anesthetics, spinal anesthesia, and block or regional anesthesia or local anesthesia. In the first year of the European War the paramount value of nitrous oxide and oxygen anesthesia in operations upon the seriously wounded, whatever their degree of exhaustion, was demonstrated by American anesthetists attached to the Western Reserve University Unit in service at the American Ambulance at Neuilly,[1] and one of the nurse anesthetists, by the special request of the French and English medical officers, remained in France after the return of this unit to America to give instruction in the technique of the administration of this anesthetic.

The extension of confidence in the value of nitrous oxide-oxygen in military surgery was attested by the conclusions adopted by the second session of the Interallied Surgical Conference held in Paris early in 1917, which was attended by delegates from England, Belgium, France, Italy, Japan, Portugal, and Serbia. In the various sections of these conclusions appear the following statements:[2]

V. *Treatment of gaseous gangrene.*—Anesthesia by means of nitrous oxide with oxygen is considered the best; when this is not to be had, ether may be substituted.

VI. *Traumatic shock.*—Local anesthesia combined with general anesthesia by means of nitrous oxide is the best. Next to this ether appears to be the least harmful. Spinal injections have produced varying results according to the surgeons employing them, especially in amputations of the lower limbs. The use of chloroform is dangerous.

VII. *Amputations.*—In the case of serious shock, the use of nitrous oxide and oxygen is desirable; ether is the next best anesthetic. Only in the case of cerebral wounds is any other anesthetic method advised.

XIV. *Cerebral wounds.*—Local anesthesia is preferred for the operation. The sitting posture tends to diminish hemorrhage and is easily maintained in secondary or delayed operations.

At a later meeting of the Interallied Surgical Conference, at which delegates from the United States and from Russia were present, as also from the countries listed above, similar conclusions were adopted.[3]

FIG. 98.—Nitrous oxide manufacturing plant. Captured German cylinders in foreground, converted for use in nitrous oxide service. One-half million gallons of nitrous oxide ready for shipment to various American Army hospitals

When the first base hospital unit of the United States Army to be called into service (Base Hospital No. 4, the Lakeside Unit) left for France it was

FIG. 99.—Storage building, office, and laboratory of nitrous oxide manufacturing plant. Dimensions, 50 by 75 feet, housing 700 tons of ammonium nitrate

equipped with what then appeared would be an adequate supply of nitrous oxide gas and apparatus for its administration.[4] During the summer of 1917 the surgeons of this unit had opportunities of testing the comparative value

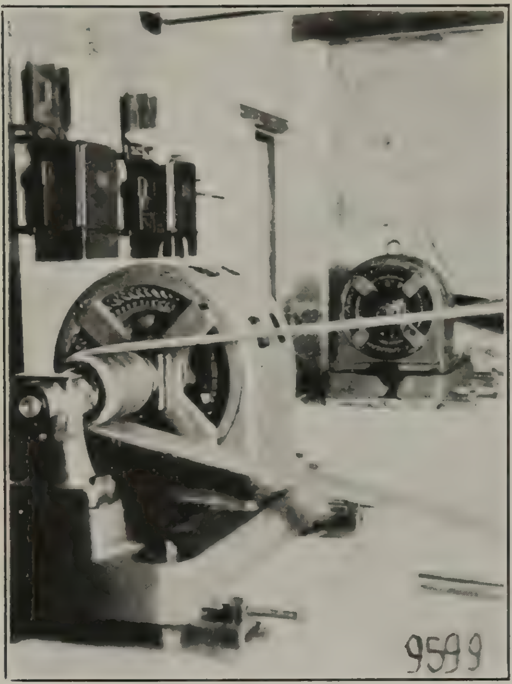

Fig. 100.—Motors of 25 horsepower, used to drive compressors

Fig. 101.—Detail of compressors. Each unit was capable of compressing 10,000 gallons daily

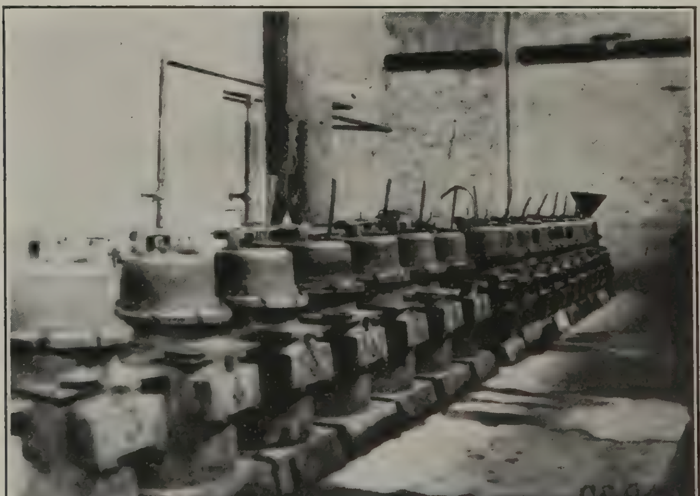

Fig. 102.—Partial view of retort room. Each retort was capable of producing 5,000 gallons per 8-hour run. The retorts numbered 30

of nitrous oxide, of ether, and of spinal anesthesia at a base hospital at Rouen (No. 9 General Hospital, British Expeditionary Forces) and at British casualty clearing stations in Flanders.[5] Almost immediately inquiries were made by both English and French officers as to the possibility of securing an adequate supply of nitrous oxide, and it became evident that the supply brought over by this unit would soon be exhausted and the English supply was inadequate for their own needs. An immediate request was therefore sent to the American Red Cross at home, and the matter was taken up with the Red Cross representatives in France, with the result that the American Red Cross appropriated funds for the purpose.[6]

FIG. 103.—Drip bottles and wash bottles which were connected with the retorts shown in Figure 102

FIG. 104.—Military balloon, used to store gas. This took the place of the usual steel gasometers

With the funds so secured a plant was manufactured. It had a capacity of 125,000 gallons per eight-hour operation and was the largest in the world at the time of its construction. It was completed, tested, approved, and shipped from Cleveland early in January, 1918; but, owing to the exigencies of transport, the shipment was lost track of after it left New York and did not reach its destination in France until May 30, 1918. No further time was lost, however. Several men trained in the manufacture of gas, who had been released from the home plant to take charge of the assembling and operation of the plant in France, within six weeks—two weeks less than the estimated time for erection—had the plant ready for operation. Unfortunately, there was

again a brief delay due to a shortage of cylinders, but this was soon overcome by the acquisition of a number of captured German cylinders which were converted for our use. The plant was then in continuous operation until about the first of January, 1919, and thereafter continued to operate intermittently for about three months, after which it was taken over by the Salvage Corps.

CRITERIA FOR THE CHOICE OF METHOD

Before indicating the choice of anesthetic method in different types of cases it may be well to give here the evidence upon which the assertion is based that nitrous oxide-oxygen in the hands of a skilled anesthetist is the anesthetic of choice for the wounded soldier, in particular for the soldier in shock or exhaustion.

As has been stated above, the choice of anesthetic lies among the inhalation anesthetics, the lipoid solvents, ether and chloroform, and nitrous oxide-oxygen, and the various agents employed in spinal, regional, or local anesthesia. In making a choice we must know (*a*) what damage, if any, is caused by the anesthetic per se; and (*b*) what protection, if any, is offered by the anesthetic per se.

INHALATION ANESTHESIA

Ether and Chloroform

In normal animals and normal men inhalation anesthetics, chloroform and ether more markedly than nitrous oxide, cause increased hydrogen-ion concentration of the blood—acidosis—during and roughly for about one hour after anesthesia. Protracted ether or chloroform anesthesia causes cytologic changes in the cells of the brain, the liver, and the adrenals identical with those resulting from other causes of exhaustion. After from four to six hours of continuous ether anesthesia many animals die; some never regain consciousness, but die within the first 24 hours. In the extensive studies of shock, hemorrhage, and gas infection made (by Lieut. Col. W. B. Cannon, M. C., and his coworkers[7]) at the Central Medical Department Laboratory, A. E. F., at Dijon, France, which have been continued in the laboratories of physiology of the Harvard Medical School,[8] it was found that "the administration of ether, from its very beginning, results in a depression of the heart and a decrease in its output, which is sufficient to account for the fall in pressure in both the normal and the shocked animals"; that in normal animals "the inhalation of strong ether results in a sudden drop in the arterial pressure which is quite temporary"; while "in the shocked animal there is no recovery of the blood pressure after the primary fall and the pressure continues to fall to zero even before the eye reflex disappears." In contradistinction to the above observations these investigators found that "nitrous oxid and oxygen, in the most favorable proportions, can be administered to the shocked animal without causing more than a slight drop in blood pressure." They state, further, that "The condition of ether sensitiveness is brought about by any circumstances which tend to depress the general condition of the animal such as low blood pressure, hemorrhage, severe operations, or the injection of acid into the circulation"—a conclusion of immediate and vital significance in its relation to the choice of anesthetic for the wounded soldier.

Ether and chloroform actively contribute to shock and exhaustion. They should be given evenly and lightly, therefore, as by the excellent Shipway apparatus, which is undoubtedly superior to the open-drop method. Marshall has shown that patients may apparently do well during ether anesthesia but

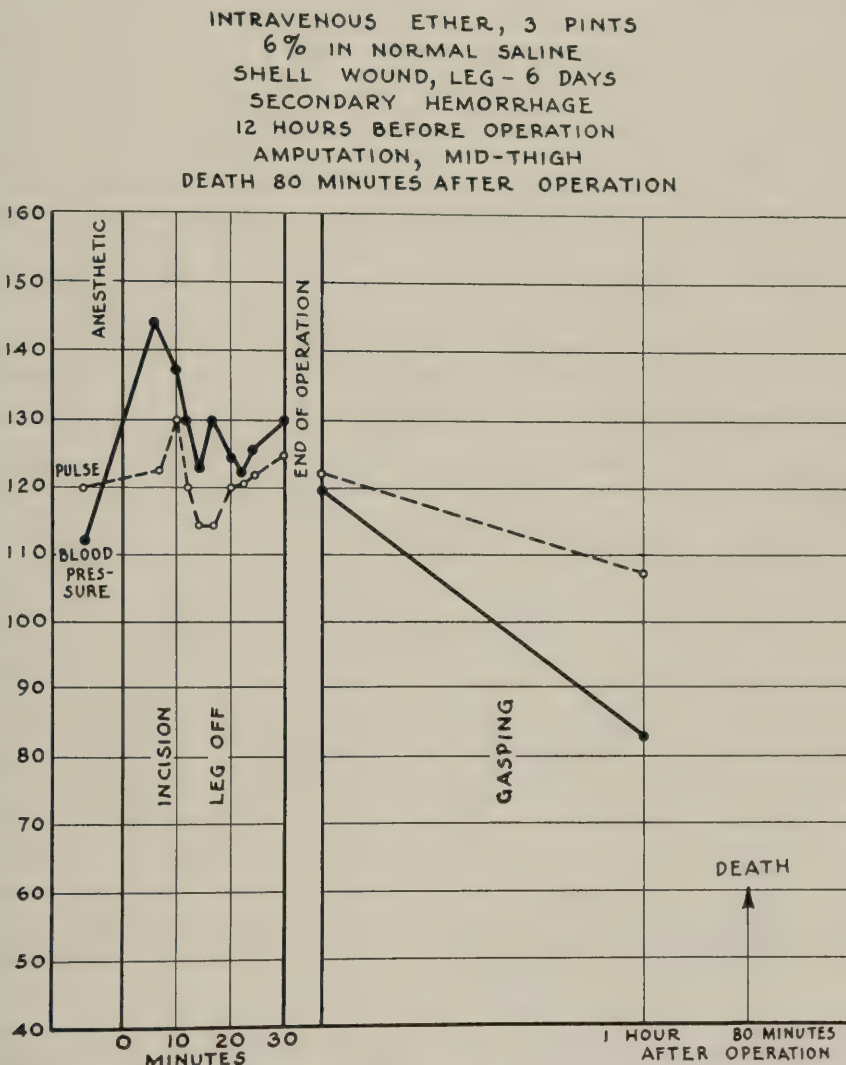

CHART I.—The effect of intravenous ether on the pulse and blood pressure. (By courtesy of Capt. Geoffrey Marshall, R. A. M. C.)

do badly afterwards; but that they do well both during and after nitrous oxide-oxygen anesthesia.[9] From the patient's viewpoint, nitrous oxide-oxygen is the choice.

NITROUS OXIDE-OXYGEN

Nitrous oxide-oxygen anesthesia is light and gives less muscular relaxation than ether or chloroform. Special training in its administration is absolutely

required, for it is technically the most difficult of all anesthetics to administer safely, although its administration is facilitated by recent improvements in the apparatus. These disadvantages, however, are far outweighed by its advantages as compared with ether or chloroform. It is quick in its action; is pleasant to take; recovery is immediate; it produces no nausea; it is protective, strongly protective against the shock of operation; for many minor operations it produces a pleasant analgesia in which pain is abolished while consciousness is retained; it can be given under positive pressure when desired, as

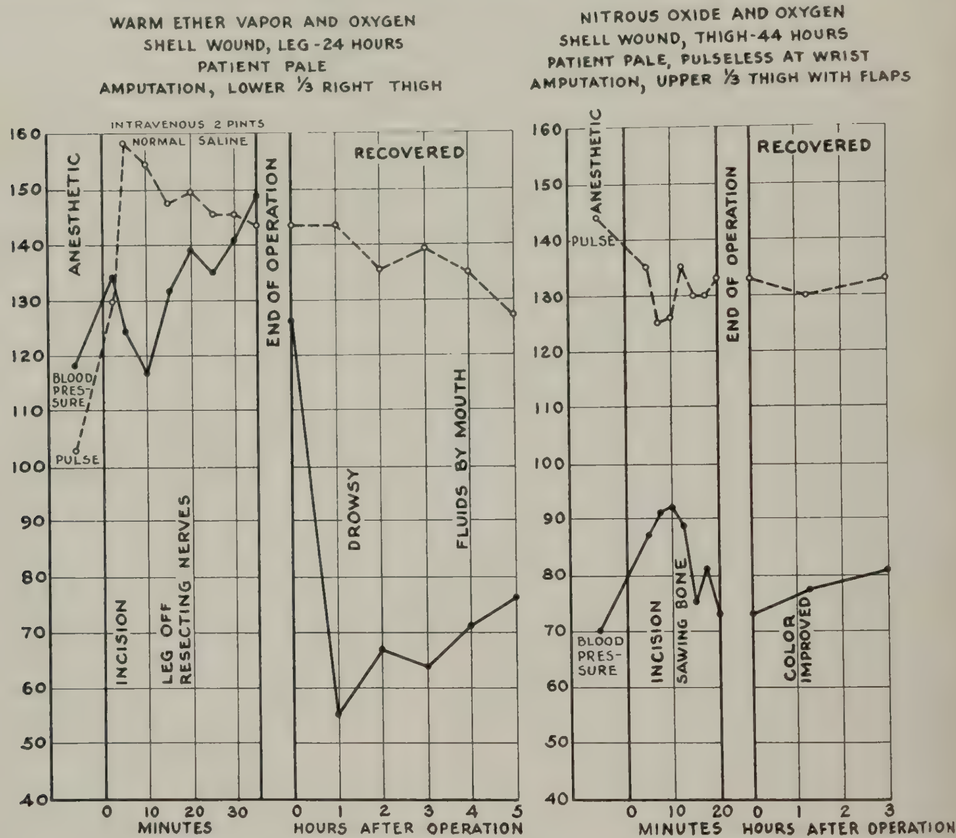

CHART II.—Comparative effects of ether and nitrous oxide in thigh amputations, as indicated by the pulse and blood pressure. (By courtesy of Capt. Geoffrey Marshall, R. A. M. C.)

in chest operations, maintaining the lung flabbily in the chest against the chest wall, or protruding out of the opening in the chest wall, as may be required.

In the surgery of the front area its quick action, its protective effect, the fact that it caused neither bronchitis, pneumonia nor nephritis, and that the patients recovered quickly so that they could eat and drink and travel soon after operation, and required less nursing care—all made nitrous oxide-oxygen the anesthetic of choice not only for routine operations, revising wounds, opening abscesses, etc., but especially for painful dressings, as it could be used repeatedly without harm. In the case of one patient in civil practice, Gwath-

mey has given nitrous oxide-oxygen 118 times; neither tolerance nor dread was established.[10]

Nitrous oxide, like ether and chloroform, must be pure. The apparatus for its administration must be capable of delivering any desired pressure and mixture of nitrous oxide and oxygen. The induction of anesthesia must be gradual, not too rapid; and respiration must be established and maintained at an even rate. The patient must be kept pink throughout the anesthesia. The pink patient can not die. If complete anesthesia can not be secured, as in alcoholics, and the patient kept pink, or if anesthesia is attained, but sufficient relaxation can not be secured and the patient kept pink by nitrous oxide-oxygen alone, then sufficient ether must be added.

As for the technique of its administration, the following points may be noted: (1) In long operations, the fixation of the anesthetic mask with a towel fastened with forceps relieves the fatigue of holding the mask. (2) If induction is slow or difficult, a few whiffs of ether help to smooth out the respiration. (3) In abdominal cases local anesthesia is useful, and during exploration ether should be added. (4) Young, robust patients are most difficult subjects—the weaker the patient the easier the anesthesia. (5) In acute hemorrhage, the absence of pink color may make it more difficult to appreciate the depth of anesthesia so that the respiration must be closely watched. (6) Because nitrous oxide-oxygen anesthesia is more difficult to give, costs more, and requires more expensive apparatus than ether, this anesthetic seems less satisfactory to the operator; but because its protection is so great, its inhalation so pleasant, its after effects so slight, it must be regarded as strictly the patient's anesthetic.

SPINAL ANESTHESIA

Marshall's [9] observations have shown that one of the immediate effects of spinal anesthesia is the fall in blood pressure (Chart III). This has been conclusively shown in laboratory experiments on animals. Marshall has shown that the fall in blood pressure is most severe in the patient whose blood is dilute—his hemoglobin low—the patient most in need of the protection of nerve blocking. In both laboratory and clinic it has been shown that no amount of trauma upon an area physiologically severed from the brain by a local anesthetic, by blocking the spinal cord or the nerve trunks, or by local infiltration, can cause shock. In this manner, as far at least as trauma is concerned, a shockless operation may be performed, but the sights and the sounds of the operating room; the patient's knowledge that his flesh is being divided by a knife; that his blood vessels are being divided and tied; the sound of the saw that severs his bones; all these contribute to psychic shock. Moreover, in a rush period the delay of spinal anesthesia does injustice to patients waiting for operation when anaerobic contamination so promptly becomes gas gangrene. Spinal anesthesia is therefore of value in all but rush periods, provided that the consequent great fall in blood pressure may be prevented and that the psychic factor may be eliminated.

As has been shown in the laboratory and confirmed in the clinic, the transfusion of blood stabilizes the circulation to the following extent: In animals that are overtransfused so that the blood pressure rises higher than the normal

blood pressure, the elasticity in the blood vessels provides a substitute for the peripheral resistance produced by the action of the vasomotor center and in consequence the blood pressure is independent of the nervous system and behaves as if it were controlled by a system of rubber tubes. After overtransfusion, therefore, spinal anesthesia, the destruction of the medulla and the cord, or even decapitation, cause no fall in the blood pressure, because the entire vascular system is not only filled but elastically distended with blood. This overdistention

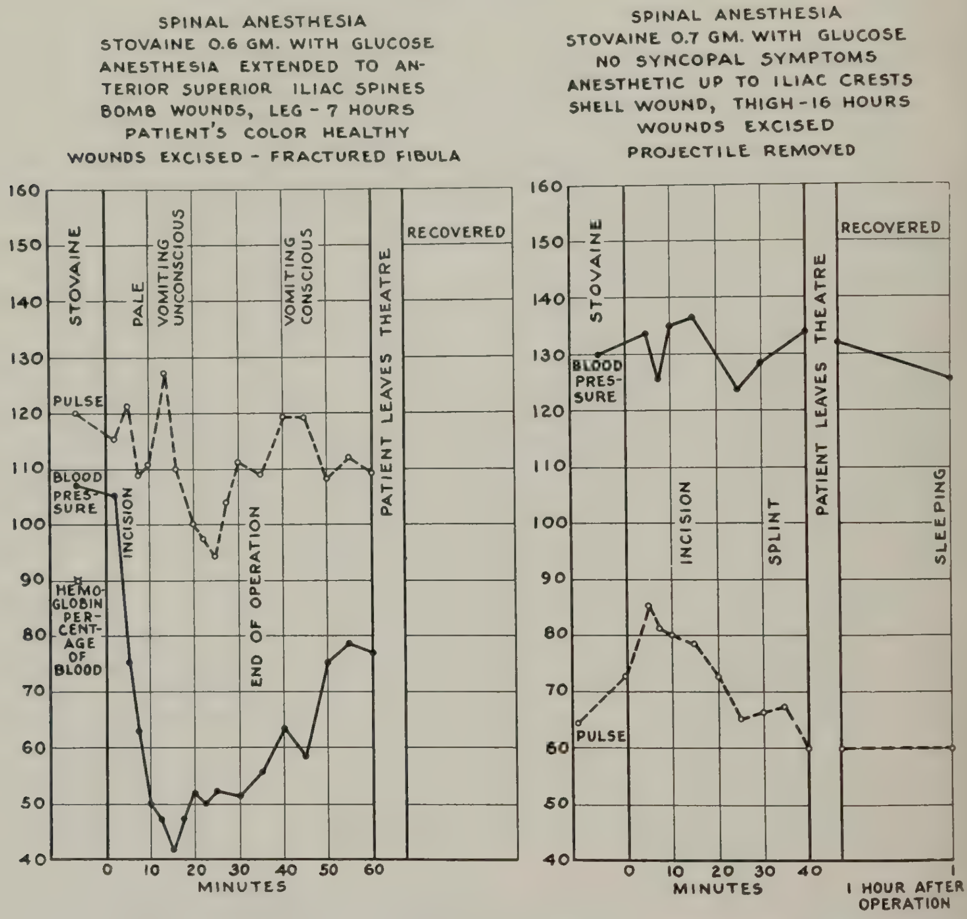

Chart III.—Effect of special anesthesia on pulse and blood pressure. (By courtesy of Capt. Geoffrey Marshall, R. A. M. C.)

lasts for one or two days. Therefore, in a case of profound exhaustion, if an ordinary transfusion of blood be given first, then spinal anesthesia may cause no serious fall in blood pressure. The other damaging factor, the physic factor, may be largely overcome by morphine, but still better by nitrous oxide analgesia, by very light nitrous oxide-oxygen anesthesia, or by light partial ether anesthesia—just enough anesthesia to eliminate psychic appreciation of the operating room and the operation itself.

Cabot made a special investigation of the value of spinal anesthesia in thigh amputations, regarding which he makes the following statement:[11]

The mortality of thigh amputations for shell wounds under chloroform or ether anesthesia was uniformly close to 40 per cent in a series of somewhat over 100 cases, this during the battles on the Somme and the early fighting in 1917, particularly at Vimy Ridge. As a result of this experience, I gave orders that all thigh amputations should be done under spinal anesthesia and detailed an officer to handle the anesthetic. In 50 consecutive cases under this technic the mortality was just under 25 per cent. At the end of this series we stopped, on account of press of work, keeping any special records, and, therefore, the observation is only on a small scale, but seems to me of definite value. We had no opportunity of comparing the effects of ether and chloroform with nitrous oxide. It is my own opinion that nitrous oxide would have made a better showing than ether or chloroform.

One of the strongest advocates of spinal anesthesia was Desplas, who summarized its advantages as follows:[12]

(1) No special anesthetist is needed. (2) Under spinal anesthesia any special treatment necessitated by the shocked condition of the patient may be easily given. (3) The possibility of pulmonary, renal, or hepatic complications such as result from general anesthesia are excluded. (4) There is no postoperative vomiting. (5) By spinal anesthesia complete relaxation of the muscles is obtained as under no other anesthesia. This condition is especially helpful in: (*a*) Extensive laparotomies, as the intestinal mass has no tendency to protrude and shock due to malaxation is thus, ipso facto, almost nonexistant. (*b*) Operations for extensive shattering of the lower members.

Desplas added that patients who have experienced both methods prefer spinal anesthesia.

As was emphasized by Rocher,[13] spinal anesthesia was of especial value in cases in which lesions in the air passages rendered inhalation anesthesia inadvisable, and also when the nature of the wound would require the maintenance of the prone position.

LOCAL ANESTHESIA

In the exigencies of war surgery, especially in rush periods at the front when apparatus for the administration of nitrous oxide-oxygen may not be available and the prolonged periods of induction and of recovery from ether or chloroform are not feasible, increased reliance must be placed upon regional or local anesthesia in combination with morphine. For the excision of contused tissues, for the removal of débris, for probing in soft tissues for missiles, for the amputation of fingers, for the repair of scalp wounds, local anesthesia may in many instances be preferable to the general anesthetic even when the latter is available; and, as indicated above in the cited conclusions of the Interallied Surgical Conference,[2] local anesthesia is the anesthetic method of choice for the repair of cerebral wounds. Certainly these operations can be accomplished under local anesthesia with a minimum expenditure of time as well as with minimum discomfort to the patient. It should be borne in mind, however, that local anesthesia may decrease the resistance of tissues which are already contaminated.

ANALGESIA

In certain cases either the time factor or the exhaustion of the patient may make it advisable not to carry the anesthetic beyond the stage of analgesia. The former factor may be dominant in cases not suitable for the employment of

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a local anesthetic, as when vascular regions or important organs are involved or wide retraction is required, or the second factor may be dominant in cases in which exhaustion from exposure, from hemorrhage, or infection has so impaired the internal respiration of the cells as to make the induction of complete surgical anesthesia menacing. An attempt to meet this problem was made by Gwathmey and Karsner,[14] who made a study of the effects of the oral administration of various combinations of anesthetics, in particular of ether and chloroform combined with liquid petrolatum. In addition to experiments on animals a clinical application of this method was made on a group of soldiers in Base Hospital No. 4, U. S. A. in service at No. 9 General Hospital B. E. F., and later by Captain Gwathmey at a casualty clearing station.

The safest method of analgesia is that induced by nitrous oxide-oxygen; when this is not available, the combination of morphine with local anesthesia or with nerve blocking provides the maximum protection.

ADJUVANT MEDICATION

Morphine

Morphine has possibilities for good and for evil which are not yet fully appreciated. Laboratory researches have confirmed what clinicians have experienced, viz, that morphine diminishes shock, prolongs life in precarious situations, such as deep hemorrhage, shock, infection; that, under morphine, patients require less food and the temperature and pulse in infections are materially controlled; that under such circumstances the morphine habit is not formed. Clinical experience shows, further, that morphine does harm when patients are cyanosed. Researches have shown that when large doses of morphine are given to animals under deep anesthesia or in acute cyanosed exhaustion from intense exertion, they are deprived of the power to overcome the cyanosis, i. e., the acute acidosis. Therefore, cyanosed patients should never have morphine.

While morphine never causes a habit when given in these extremely critical states, it easily establishes a habit when given in cases of psychic distress, in worry, insomnia, etc. There is opportunity for wide discrimination in its use—in one case, none should be given; in another case, light doses may be beneficial; in other cases massive doses are most useful. When the way is clear so that massive doses of morphine may be given safely, it is a most potent agent. In the surgery of war it was of paramount value when used as an adjuvant to general or local anesthesia.

Magnesium Salts

In the laboratory it has been found that to a limited extent the intravenous administration of magnesium salts is apparently a strong agent in promoting intracellular restoration. Intravenous infusions of magnesium salts lower the respiratory rate, and induce a state resembling sleep. This magnesium "sleep" lasts approximately two hours. The good effects of the infusion are well sustained. Not only are the clinical results apparently good, but a study of the effect upon the cytologic changes in the liver cells in exhaustion shows a diminution of the edema, not as marked but similar to that resulting from normal

sleep. It is possible, therefore, that the magnesium salts partially exert the effect of sleep in aiding cellular repair; but the magnesium salts alone, in good dosage, are cardiac depressants. Their use is under observation, their value not established.

METHODS IN SPECIAL GROUPS OF CASES

As stated at the beginning of this chapter, in discussing the anesthetic method of choice in special groups of cases it is impossible entirely to separate the anesthetic from the other factors of the operative management. It is obvious that in the case of the wounded soldier, as of the civilian patient, the management of the operation implies the closest cooperation between the surgeon and the anesthetist. For this reason, in the following summary the operative factors which war experience demonstrated to be of primary importance, are included with the discussion of the anesthetic method of choice in each case.

Shock and Exhaustion

Among the memoranda issued from the Division of Laboratories, A. E. F., those relating to traumatic shock and hemorrhage contain the following statements regarding anesthesia.[15]

Clinical observations have shown that after the body has been damaged by a shock blood pressure there is great sensitiveness to ether and chloroform anesthesia. Experimental tests have proved that a degree of anesthesia which abolishes in a shocked animal the simple reflexes may cause the arterial pressures to fall rapidly 20 mm. of mercury or more. In a series of human cases the fall of pressure during operation averaged 30 mm. of mercury—a disastrous drop in view of the already existing low pressure. There are two ways of avoiding this harmful change—by use of nitrous oxide and oxygen as an anesthetic and by sustaining the pressure if ether is employed.

Clinical and experimental observations have demonstrated that if anesthesia with nitrous oxide and oxygen is properly produced a shock blood pressure need not be lowered at all during the course of operation. Preoperative administration of morphine should be followed by *expert* use of nitrous oxide and oxygen in the ratio of not more than 3 parts nitrous oxide to 1 part oxygen. A higher ratio may cause as great a fall of pressure as is produced by ether. Deep anesthesia and cyanosis are to be avoided at all times. The surgeon must adjust himself to this light anesthesia, and its consequent absence of complete relaxation, by patience and gentleness and by a larger operative incision when necessary.

If nitrous oxide and oxygen are not available, ether given by the drop or vapor method should be employed. As soon as the anesthetic is started, however, a blood transfusion or an infusion of gum-salt solution should be started and allowed to continue slowly. The head of arterial pressure is thus maintained and may even be raised during the period when it otherwise would be much lowered.

Chloroform and ethyl chloride, which are even more depressant to the circulation than ether, are to be employed only when no other means of producing anesthesia is obtainable.

The foregoing directions are approved by the Chief Consultant in Surgery of the American Expeditionary Forces.

In brief it may be stated that for the soldier in shock or exhaustion, whatever the nature of the wound, the primary requisites are physiologic rest, fluids by every possible route—by mouth, by hypodermoclysis, by intravenous injections—elevation of the foot of the bed; morphine if there is no cyanosis; transfusion of blood; quick, deft, light operation. The anesthetic of choice, as has been sufficiently indicated above, is nitrous oxide-oxygen analgesia combined if possible with local or regional anesthesia.

Abdominal Operations

If nitrous oxide-oxygen is used and it is the anesthetic of choice, regional infiltration with novocain should be employed also to promote relaxation of the abdominal muscles. If relaxation is not complete then ether should be added but only during the exploration.

If ether is employed Gwathmey's warmed vapor technique, combined with local infiltration, is the best method of induction.[16]

As Marshall has emphasized, the patient should be turned from side to side as little as possible during operation. The abdomen should be kept open the

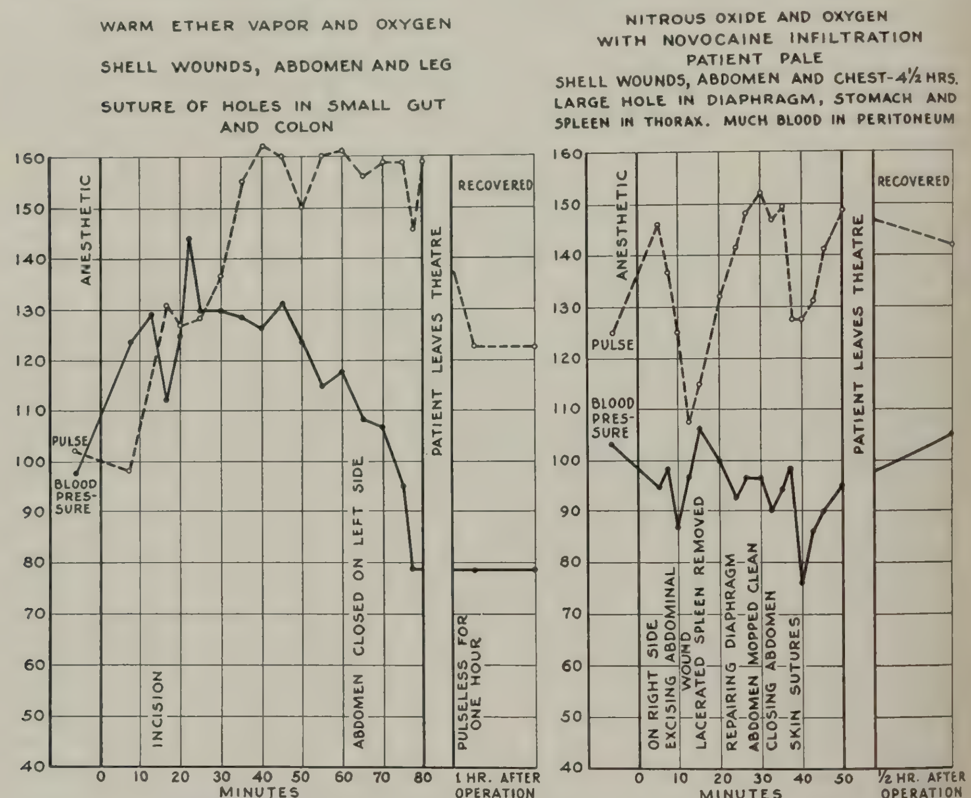

Chart IV.—Comparative effects of ether and of nitrous oxide in operations for the repair of extensive abdominal wounds. Note the greater extent of the trauma in the second case, which received nitrous oxide. (By courtesy of Capt. Goeffrey Marshall, R. A. M. C.)

least possible length of time. Manipulations and exposure of the viscera should be reduced to a minimum; therefore, an ample incision should be made.[9] If the patient is in deep shock, a transfusion of blood should be given at the beginning and again at the close of the operation.

Operations on the Chest

An extensive research was carried out by Gwathmey and his associates at the Central Medical Department Laboratory, A. E. F., at Dijons, France, for the purpose of determining the anesthetic method of choice.[17] The findings in this study were in accord with the clinical experience of Marshall, of the

writer, and of others, that nitrous oxide-oxygen under positive pressure is the method of choice. The following statements regarding the anesthesia in chest surgery were made by Lockwood:[18]

Paravertebral anesthesia is administered two or three spaces above and below the wound. A local infiltration at some distance from the wound is employed.

Novocain 5 per cent and potassium sulphate 0.25 per cent in normal saline, prepared fresh and repeatedly autoclaved is injected with a Gray's syringe (10 mms. of adrenalin per ounce are added just before use). Gas and oxygen should be available for administration while the hand is inside the chest or when the patient is restless.

The most serious cases may be operated on with a light nitrous oxide analgesia. Local anesthesia combined with gas and oxygen is the best means of preventing shock in extended operations. Neither ether nor chloroform should be used in chest surgery.

An official report on intrathoracic surgery contains the following section on anesthesia:[19]

A simple method of giving nitrous oxide and oxygen, utilizing tank pressure, to secure needed degree of inflation, was devised by Captain Gwathmey. A full preoperative dose of morphine made possible the induction of deep analgesia, without increasing the nitrous oxide and oxygen rates above 3 to 1, which Lieutenant Colonel Cannon's experiments had proved to be the limit of safety in the presence of shock. Lieutenant Cattell's observations had indicated that morphine thus given had value as a prophylactic agent against oncoming shock, and therapeutic value when given early in the presence of shock. No untoward result from depression of the respiratory centre was noted.

Animal experiments showed clearly that administering anesthesia under tension, particularly when the chest was opened, was dangerous if the gas or ether was given in increased concentration. It also demonstrated that thoracotomy with all incidental manipulations, such as dislocation and operation upon lungs, should be performed under the primary stage of anesthesia. Manometric observations showed that when the pressure present in the mixing bag reached 8–16 mm. Hg. it sufficed to distend the lungs completely; that degree of pressure is present when the bag fluctuated little during inspiration. Since this degree of tension in the bag produced an intrapulmonary pressure that was well within the limits of safety for dogs, the manometer was not deemed a necessary adjunct for human use.

A safe sequence in practice was found to be as follows: After the effect of the preoperative hypodermic of morphine was present, administrations of pure oxygen under no tension were started. Then very gradually the pressure was increased, and the administration of nitrous oxide started. Rapid induction of the anesthesia was undesirable. Avoidance of excitation and the producing of gradually increasing inflation were essential. During the operation the proportions of the gas-oxygen mixture and the pressure transmitted to the trachea were varied to meet conditions. After the parietal pleura was closed the amount of nitrous oxide was gradually reduced; last of all, oxygen under pressure was continued until the patient was conscious.

The American Red Cross nitrous oxide apparatus, perfected by Captain Gwathmey and adopted by the Army, fulfilled every requirement. This apparatus provides a mask that can be rendered relatively air-tight by close approximation to the face, an escape valve, a mixing bag close to the inhaler, and a rough gauge for estimating the proportion of the gases.

Intrapulmonary pressure was raised by increasing the rapidity of the flow of gases from the tank and by increasing the pressure upon the face piece. It was lowered by decreasing the rate of flow of the gases or by releasing the valve or decreasing the pressure which held the face piece in place. Thus, any degree of desirable inflation or deflation was promptly available to meet operative requirements. In general the degree of pressure utilized was that best suited to the animal or man under operation.

This method gives all practical requirements for intrathoracic surgery without necessitating deep anesthesia for the introduction of intratracheal or endopharyngeal tubes. Moreover, its safety and ease of control has removed the chief obstacle to a wider application of surgical therapy.

On the basis of his large experience in France and at the Walter Reed Hospital since the war, Keller makes the following statement:[20]

Nitrous oxide is, in my opinion, the anesthetic of choice in war-time general surgery and its general use in all formations from front to rear during the late war was limited only by lack of trained anesthetists and difficulty of transportation to some front line formations. Its use is also somewhat limited for mobile warfare such as during a rapid advance.

In chronic chest surgery nitrous oxide is absolutely the inhalation anesthetic of choice, especially when combined with the Crile novocain block or paravertebral block, which enables the operator to do chest work without passing the stage of analgesia.

Nitrous oxide used in the above manner has lowered the operative mortality in the chronic thoracic surgical derelicts to a degree not attainable with other inhalation anesthetics.

It is of interest to note also that in the section on chest surgery in a questionnaire sent by the Research Committee of the American Red Cross to base hospital staffs in France the following preferences as to the anesthetic were expressed:[21] Local anesthesia if possible was recommended by all. For general anesthesia, the stated first choice was as follows: Gas oxygen, 18; ether, 9; warm ether, 3; chloroform, 2.

To summarize, in intrathoracic surgery, if there is cyanosis, oxygen should be given under pressure with enough nitrous oxide for analgesia until the gray-blue color or the ordinary cyanosis gives place to a pink color. This will usually require from 10 to 15 minutes. When the pink color has been restored the anesthetic may be deepened as required. With the gas and oxygen apparatus the lungs can be inflated under positive pressure, cyanosis overcome and anesthesia maintained; and under high pressure both anesthesia and sufficient lung ventilation can be maintained even when both sides of the thorax are widely and simultaneously opened.

An adequate exposure should be made. Resecting a rib is better than working in a cramped space. The lungs and heart and pleura should be handled precisely and gently. The patient should be moved as little as possible, the chest closed air-tight. Oxygen should be given under pressure at intervals during the first 24 hours, as the condition of the patient may indicate.

Operations on the Extremities

Nitrous oxide-oxygen is the anesthetic of choice, but if it is not available then low spinal anesthesia by Cabot's method may be given, but in such a case it is necessary to be prepared to give a blood transfusion to overcome the low blood pressure which will be caused by the anesthetic.

When dealing with fractures under anesthesia, no less than without anesthesia, the limb should be orientated and handled so skillfully that little or no crepitus will be felt. In amputations the nerve trunks should be divided as lightly as possible and the limb handled as little as possible. In grave shock, if no nitrous oxide is available, low spinal anesthesia by Cabot's method may be used and preparations made to give blood transfusions to overcome the lowered blood pressure caused by the anesthetic. Large wounds should be covered and protected as much as possible. (Chart V.) (See also Chart II.)

Gassed Cases

Oxygen under pressure should be given first, with just sufficient nitrous oxide to eliminate the worry due to the mask and to the oxygen inhalation. After the pink color is restored, light surgical anesthesia may be induced. The operation should be short and deft. As required, oxygen under pressure should be given during the post-operative period. In these cases if nitrous oxide is not available, local, regional, or spinal anesthesia should be employed rather than general anesthesia.

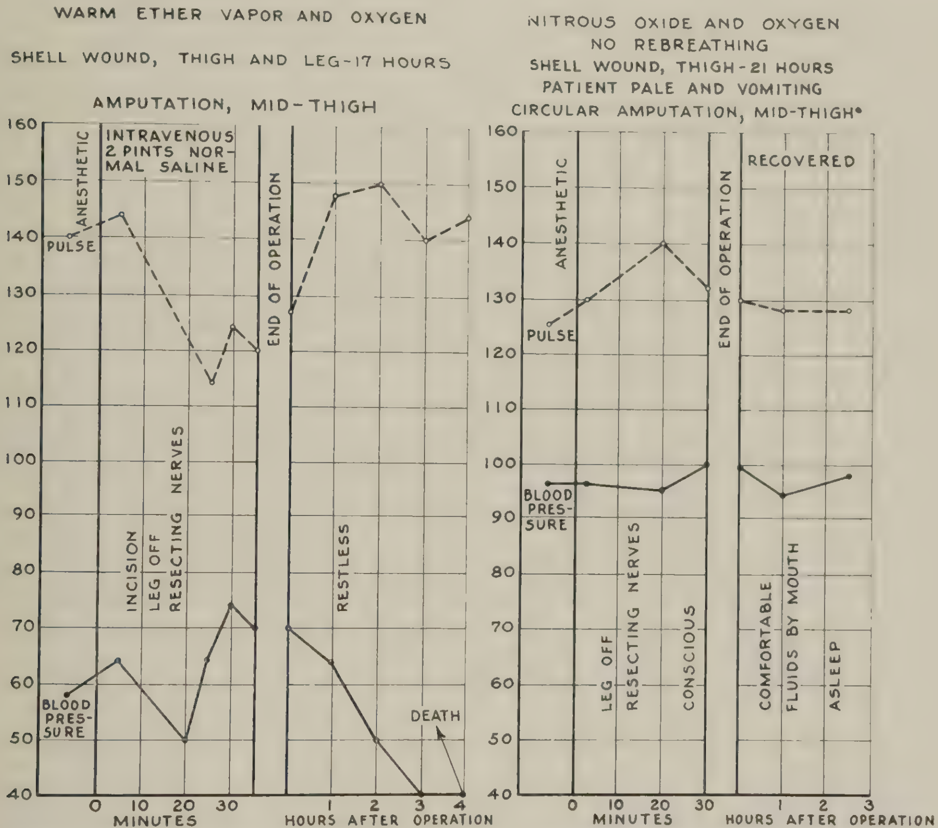

Chart V.—Comparative effects of ether and of nitrous oxide in thigh amputations as indicated by the pulse and blood pressure. (By courtesy of Capt. Geoffrey Marshall, R. A. M. C.)

In cases of phosgene poisoning it should be borne in mind that phosgene poisons by reason of its interference with the passage of oxygen through the walls of the air vesicles, thus producing anoxemia. Cases of phosgene poisoning, as is indicated by the rapid respiration, increased pulse rate, cyanosis, loss of mental and muscular power, sweating, etc., are in a state of acute acidosis—the same end effect as is produced by prolonged inhalation anesthesia, by exertion, fever, emotion, shock, exhaustion, etc. Therefore, since the inhalation anesthetics themselves cause acidosis, their administration adds one acidosis to another; i. e., the acidosis of anesthesia intensifies the acidosis of phosgene asphyxia. Surgical shock also produces a state of acidosis. The

acidosis of the surgical operation, therefore, if added to the acidosis of the phosgene and the acidosis of the anesthetic may kill the patient.

Therefore, when an operation is required in a case of phosgene poisoning, it should be performed under local, regional, or spinal anesthesia, the patient meanwhile being kept pink by oxygen under pressure by means of the positive pressure mask of a nitrous oxide apparatus or a Haldane apparatus. If there is a phase of operation that can not be controlled by local or regional or spinal anesthesia, then one should give oxygen under pressure until the patient has a pink color, then switch to nitrous oxide for the briefest time required for the operative move, then switch back again to oxygen under pressure.

Operations in the Presence of Acute Infections

While narcotization with morphine is of value in all cases excepting in the presence of cyanosis, in the acute infections, as has been proved by experiment and demonstrated repeatedly in civilian and war hospitals, morphine is of paramount value. In such cases, therefore, the first requisite is deep narcotization with morphine, and if time permits the subcutaneous infusion of 1,000 c. c. of normal saline solution before operation. Nitrous oxide-oxygen analgesia should be used, the stage of full anesthesia being induced only as the exigencies of the operation demand. The morphine narcotization and saline infusions should be continued until the patient is safe.

CONSENSUS OF OPINION AMONG BASE HOSPITAL STAFFS

The questionnaire already cited contained, as would be supposed, special sections regarding the value of different types of anesthetics. For details in connection therewith consult the appendix of this volume.

LIMITATIONS OF DIFFERENT TYPES OF ANESTHESIA

The problems presented by anesthesia in war surgery, as in civilian surgery, are in effect problems of limitations. Therefore, since in the exigencies of military surgery the anesthetic method of choice may not always be available, it is peculiarly essential that the limitations of each type of anesthetic be kept clearly in mind.

Spinal Anesthesia

In the low blood pressure of acute shock or hemorrhage the additional fall due to spinal anesthesia as a result of the interruption of so large an area of vasomotor nerves may cause dangerous, even fatal collapse. This may be prevented by blood transfusion. The psychic factor may be both distressing and damaging, but may be eliminated by very light ether anesthesia. Occasionally spinal anesthesia is incomplete. Such a failure must be met by a general anesthetic.

Nitrous Oxide

In abdominal operations muscular relaxation may not be complete under nitrous oxide anesthesia. The condition should be met by regional anesthesia of the abdominal wall and by light handling.

Nitrous oxide is a light anesthetic, demanding of the surgeon a light deft operative technique. Nitrous oxide must be given only by experts; it is dangerous in inexpert hands.

Ether

Ether tends to cause bronchopneumonia, especially in abdominal operations during the winter. It diminishes, even temporarily abolishes, phagocytosis, and is therefore unsuitable in infections. There is a tendency to a fall in blood pressure after operation; hence it is unsuitable in shock. Ether causes a rather large diminution in the reserve alkalinity of the blood.

THE ANESTHETIST

If, as has been demonstrated, nitrous oxide-oxygen is the anesthetic method of choice in military surgery, then it is essential that corps of anesthetists especially trained for its administration should be available. Safest of anesthetics in expert hands, nitrous oxide is the most unsafe in the hands of the inexpert. Since in military surgery the majority of patients are already grave risks on account of exposure, exhaustion, and infection, it is peculiarly necessary that the anesthesia should be handled by trained hands.

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CHAPTER VII

WOUND SHOCK [a]

Wound shock occurs as a consequence of physical injury—the rupture, shredding, tearing, or crushing of large amounts of tissue. It is characterized by low venous pressure; low or falling arterial pressure; rapid thready pulse; diminished blood volume; normal or increased erythrocyte count and hemoglobin percentage in peripheral blood; leucocytosis; increased blood nitrogen; reduced blood alkali and lowered metabolism; subnormal temperature; cold skin, moist with sweat; pallid or grayish or slightly cyanotic appearance; thirst; shallow and rapid respiration; of ten vomiting and restlessness; and anxiety, changing gradually to mental dullness and lessened sensitivity. These features may appear at once or as soon after the reception of the wound as observations can be made, or they may develop only after several hours. The former type is called primary, the latter secondary, wound shock.

The factors concerned in the development of shock may be divided into those that initiate the condition and those that sustain it after it has once been developed.

INITIATING FACTORS

The onset of early or primary shock is most reasonably accounted for as a consequence of some disturbance of the nervous system. A review of shock theories has shown that it is impossible to eliminate, as a consequence of wounds, a reflex relaxation of blood vessels similar to that which occurs in fainting. Indeed, fainting is not infrequently seen after the reception of relatively slight wounds in warfare. Vincent [1] observed cases of this character, but the only instance which he described in detail is that of a man wounded in the abdomen who, through manifesting the syndrome of shock a few minutes after being hit, had a rise of blood pressure from 60 to 90 mm. Hg. within 45 minutes thereafter. It is possible, therefore, that an effect similar in character to fainting or syncope may be produced by a wound and that it may persist for a longer period than the usual fainting spell.

For an explanation of the onset of delayed or secondary shock the theories which have been most commonly advocated in the past, such as inhibition, reduction of the carbon dioxide content of the blood (acapnia), fat embolism, and an exhaustion of nerve centers or certain glands, have all been shown to be inadequate. Their chief and common defect is that they fail to account for the occurrence both in clinical and experimental shock of a diminution of blood

[a] This chapter is based largely on the writer's experience in cooperation with British investigators at a casualty clearing station at Bethune during the summer of 1917, and in London during three months of the winter of 1917-18, and thereafter on the work of a group in the Laboratory of Surgical Research of the American Expeditionary Forces, at Dijon, France, during eight months of 1918. The members of the group had opportunity to observe shock cases in forward areas, both during the summer and in the fall of that year. The experimental and clinical observations in France and England were supported by laboratory investigations conducted simultaneously in the United States.

volume and either a local or general concentration of blood corpuscles. A group of theories which do take these facts into consideration, namely, theories which postulate a primary vasoconstriction with a consequent capillary congestion, are defective in that they do not suggest how a vasoconstriction would occur capable of bringing about a reduction of blood volume. The theory of secondary shock which has the strongest support, both in clinical observations and in laboratory experiments, is that of a toxic factor, arising from damaged and dying tissue and operating to cause an increased permeability of the capillary walls and a consequent reduction of blood volume by escape of plasma into the lymph spaces. Thus the concentration of the corpuscles is also readily explained. It is recognized that after a sufficient time infection may occur and be of such character in itself as to induce a persistent low blood pressure. According to this theory there might be no essential difference between the effects of toxins given off by damaged tissue and of toxins resulting from activity of bacteria.

Emphasis should be laid on the fact that toxic agents are usually not working alone to bring about the shock state. Complicating the wounds there is usually some loss of blood. Under battle conditions, especially, there may be cold and exposure. Likewise there may be prolonged lack of food and water. Sweating is a regular accompaniment of severe trauma. All these factors are known to be capable of playing a rôle in producing a more or less permanent fall of pressure; such a loss, when combined with injury, may bring about promptly the signs of wound shock. Similarly, after a serious wound, with loss of blood, shock may not be present, but then ether or chloroform anesthesia and operation may quickly induce a calamitously low blood pressure. It is because the state of shock may be the result of a group of circumstances that improvement often follows when one easily controllable factor (e. g., cold) is eliminated.

SUSTAINING FACTORS

When a low blood pressure is developing in consequence of the action of initiating factors a critical level is reached at about 70 mm. Hg. Below this level the delivery of oxygen to the tissues becomes inadequate, the blood alkali begins to be reduced (i. e., "acidosis" appears), and the rate of chemical change within the organism becomes slower. There is a diminished heat production, so that the body temperature gradually falls below normal.

When there are defective circulation and insufficient oxygen supply tissues are damaged. Most sensitive to oxygen want are the nervous tissues. In addition to injury to these delicate structures there is likely to be a relaxation of the walls of capillaries and perhaps also injury to the capillary endothelium. These disturbances in elements which are essential to the maintenance of an efficient circulation continue the state of shock which has been originated by other factors, and they may also still further reduce the already low arterial pressure.

EARLY TREATMENT

In the following suggestions for the treatment of the wounded who are suffering from shock or who, because of their wounds, may pass into a state of shock, the facts above mentioned will be applied. It is necessary to keep in

mind at the outset that the early use of simple measures is of prime importance. Such measures will be described in relation to the conditions that have to be met in the course of treatment.

Hemorrhage

It is well known that bleeding may sensitize the organism to factors which are likely to induce shock, and furthermore that men who have been severely wounded and are in an unstable condition therefrom may be reduced to shock by relatively slight hemorrhage. Moreover, in association with serious wounds there is likely to be a considerable loss of blood and consequently urgent need that no more be lost. All these considerations strongly emphasize the importance of employing measures which will prevent a further bleeding that may be of critical importance to the life of the individual.

The readiest method of checking hemorrhage when a limb has been wounded is by means of a tourniquet, and there is usually strong temptation to apply it promptly. As mentioned above, however, there is good evidence of a toxic factor in shock. Part of the evidence for the existence of this factor was obtained in cases of a long exclusion of the circulation from a part of the body—especially a wounded part. When the blood flow was restored in the anemic region in these instances shock was promptly produced. Cases of this character illustrate a definite danger which may arise if a tourniquet is used to control hemorrhage and consideration is not given to the length of time it has been in place. The evils of thoughtless and indiscriminate use of the tourniquet became so prominent during the war that in certain parts of the British Army this method of hemostasis was definitely discouraged. Medical officers then found that in most cases the flow of blood could be stanched by applying compression to the wound itself. The advice of Wallace and Fraser,[2] who had a vast experience with shock cases during the war, is as follows:

> Bleeding is to be arrested by pressure upon or ligature of the bleeding point itself and not by constriction of the limb above or by tying the artery on the proximal side of the injury. The systematic use of the elastic tourniquet should be limited, and its use, apart from during an operation, should be restricted to those cases in which a limb is completely smashed or blown away, or as a temporary measure while a patient is being carried to a regimental aid post. If the medical officer finds that a tourniquet has already been applied it is his duty to remove it at once and to examine the limb so as to ascertain whether there is actually hemorrhage, and, if so, to take measures for its arrest.

A rule which is generally applicable is that the tourniquet should be avoided altogether if possible, and that if one is absolutely required it should be placed as far from the trunk as conditions permit and removed as soon as vessels are tied or snapped. If it must be left long in position a note should be attached to it stating when it was applied.

The suggestion has been offered that if a limb has been so badly mangled that it can not be saved a tourniquet should be set close above the trauma and left in place until after amputation. The amputation should be performed proximal to the tourniquet. Thus the body is protected against toxic material which is present in the torn and smashed tissues and is likely to be absorbed.

Loss of Body Heat

The well-established association between the incidence of shock and loss of body heat emphasizes the urgency of taking every precaution to conserve the store of heat which the body has and to give back to the body the heat that may have been lost. In accordance with this observed relationship the following principles of treatment should be applied.

When a wounded man is being examined he should be subjected to as little exposure of the body as possible; only one part should be exposed at a time and it should be promptly covered again. These precautions are especially necessary in cold weather. As soon as possible the patient should be surrounded with blankets. Whether he is lying on the ground or on a stretcher, more blankets, if available, are needed under the body than over. The reason for this is that the blanket protects against heat loss by the air which it holds enmeshed in its fibers. The weight of the body lessens the air space in the fabric and consequently reduces the amount of protection. Under military conditions it is necessary to reduce the number of blankets to a minimum. By using the

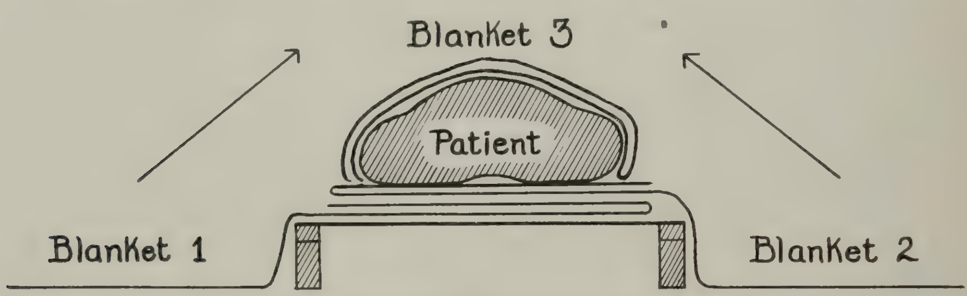

Fig. 105.—Method of folding three blankets to provide four layers beneath and four above the patient. The outer ends of blankets 1 and 2 are folded over the two layers of blanket 3, already in place above the patient

method illustrated in Figure 105, three blankets may be made to provide four layers above and four below the patient. Of course the feet should be wrapped in warm covers.

If the patient already is cold or is likely to lose heat despite blanketing his body may be heated by means of hot-water bottles. If there are insufficient bottles in the medical supplies for the purpose the ordinary canteens may be used instead. Great care should be exercised to avoid a degree of heat which might cause burns. The bottles are more effectively employed if both sides instead of one are brought into contact with the body. Further, the physical fact should be remembered that heat passes faster from a warm to a cold object than to a lukewarm object, and, finally, heat is distributed throughout the body by the circulating blood. In accordance with these considerations one hot-water bottle should be laid on the abdomen, and the hands, which are likely to be cold, placed over it. The second bottle should be placed between the feet, which also are likely to be cold. If more bottles are available they should be placed between the thighs or pushed toward the axilla between the arm and chest on either side. By such distribution the heat passes chiefly to the body rather than in large part to the layer of air in the surrounding blankets; further-

more, it warms the parts which are most likely to be or to become chilled when the circulation is poor.

Another highly effective mode of contributing heat to the body is by means of hot drinks. There are, however, limitations to the use of this method, for in case of wounds of the alimentary tract the taking of fluid would be likely to wash material into the peritoneal cavity, and, besides, fluid taken by mouth is sometimes not retained by the severely wounded. If the gastrointestinal canal has not been opened by injury and if the swallowed fluid is not vomited a hot drink is by far the best method of warming. All of the heat in it above the temperature of the body passes to the body itself. Moreover, the fluid helps to restore a reduced blood volume. It also satisfies the distressing thirst which is so constantly complained of by the wounded. The hot drink may be given in forms which are relished, such as hot tea or coffee. Under military conditions these drinks may be provided at advanced stations and may be given repeatedly, when they are tolerated, in the course of the journey to a permanent hospital.

Preliminary dressing of wounds should be done, if possible, in a warm place. In military activities this is a rare possibility, but provision should be made in advanced dressing stations for keeping the patient warm during the first care of his wounds. An arrangement which has proved simple and satisfactory in military service is that of providing in these stations a rectangular support, the length and width of a stretcher and about 3 feet high, which is surrounded by blankets and heated by a lamp or oil stove placed on the floor. Over this warm chamber stretchers may be set and patients thus kept warm during the examination of their wounds. If the layer of warm air which is ordinarily retained in garments is replaced by moisture the loss of heat through this better conductor may be rapid. During the preliminary dressing outer clothing which is wet should be removed and replaced by more blankets. If the patient can be kept warm, however, this need not be done.

During the World War an important improvement in the care of the wounded, especially in cold weather, was made when devices for warming the motor ambulances were installed. Some accidents occurred from escape of gases into the car when the exhaust was used to supply the heat. Cars may be heated, however, by hot water from the radiator.

When, on arrival at the hospital, the patient has a low temperature and cold skin his clothing should be promptly removed or cut away (with care not to lose more heat) and he should be put in a warm bed. A highly effective means of warming the patient while in bed is to set over him fracture frames which are covered with blankets and then to introduce heat into the covered space. If electricity is available a permanent arrangement for this purpose may be made by wiring six or eight electric lights so that they project inward from the frame. Another device which may be used in the absence of electricity is that of leading from near the floor to the space under the fracture frames an elbowed stovepipe and using as a source of heat a lamp or alcohol burner set on the floor under the lower end of the pipe. It is advisable to pass the pipe through a wooden board shaped like the end of the frame so as to avoid danger of burning the bedclothes.

Great care should be exercised not to overdo the heating. A shocked man is suffering from reduced blood volume and should not be made to lose unnecessarily more fluid from his body by sweating.

The clinical improvement seen when a wounded man, cold and shocked, is merely put to bed and warmed is often astonishing. The pulse, absent at the wrist, may return in good volume, and within an hour, as the patient becomes warm, the blood pressure may rise to a satisfactory level.

Pain and Restlessness

Experimental tests have shown that the agitation of a broken bone in damaged tissue results in a sharp fall of blood pressure—an effect which may be accounted for by further trauma and by the liberation of more toxic material. Experience during the years of the war proved to British surgeons that the use of the Thomas splint in bringing in the wounded did more, perhaps, than any other agent to reduce the incidence of shock. The lesson of these facts is that when, in a serious injury, a bone is broken, it should be carefully splinted before moving the patient. This precaution is especially important in fracture of the femur, with the possibility of damage to the large muscle masses which surround the bony fragments. The benefits of splinting arise both from lessening the occasion for pain and from minimizing further destruction of the soft parts by movement of the broken fragments.

When the transporting of a severely wounded or shocked man is likely to last for a considerable period and to involve a good deal of agitation and jarring, as is the case in military operations, his chances, unless infection is developing rapidly, are improved by stopping occasionally and giving him opportunity to be warmed, rested, and supplied with fluid. Opportunities of this character usually are offered in warfare at the battalion aid post and the dressing station before the hospital is reached. Commonly an ambulance service is eager to make a record for rapid transportation of the wounded. This attitude should be tempered by the judgment of the surgeons, who should not permit the seriously wounded to be rushed to the next station before showing the improvement which arises from warmth and rest.

Concerning the use of morphia, there have been differences of opinion. It has been given hypodermically even in as large a dose as 1 grain to badly wounded men. Crile and Lower [3] advocated giving the drug to the point at which the respiration sinks to at least 12 per minute. On the other hand, Marshall,[4] who had a very large experience in anesthetizing shocked men, testified that the severely wounded, deeply under the influence of morphine, make an unsatisfactory recovery after operation. The object to be sought in giving morphine is to blunt the feeling of pain and to lessen anxiety, especially during a rough and dangerous carry, and to reduce or abolish the restlessness which is wasting the patient's energy and making a great demand on his defective circulation. As experiments have proved, after morphine the blood pressure may be lowered further without producing acidosis than is possible otherwise, an observation which suggests that morphine lessens metabolism at a time when the oxygen, needed for the maintenance of chemical changes

in the cells, is likely to be insufficient. The drug should be given, therefore, until the patient is comfortable and quiet. In some cases one-fourth grain may be sufficient, in others one-half grain may be needed. The dose should be repeated if necessary.

Low Blood Pressure

If simple measures such as warmth and rest do not result within an hour in producing a rise of systolic pressure to at least 80 mm. Hg., other means should be used to raise it. Evidence of extensive hemorrhage associated with a very low blood pressure would warrant radical interference as soon as the patient is warm. The decisively harmful effects of prolonged insufficient volume flow of blood, which have been previously emphasized, should always be kept in mind.

To rationalize the treatment of low pressure, the facts already developed should be applied. It should be remembered that the blood is serviceable to the tissues only as it flows through the capillary region, and that the prime cause of the low pressure in shock is a diminished volume of blood in circulation; furthermore, that apparently the stagnant blood is not in the arteries nor in the veins, but is concentrated in capillary areas. With these considerations in mind we may regard critically the proposals which have been made for improving the circulation.

POSTURE

For many years in civil hospitals shock cases have been treated by raising the foot of the bed so as to permit gravity to aid the return of blood from the large veins of the abdomen to the heart. There is some evidence that in normal individuals the blood pressure in the head-down position may be increased approximately 15 mm. over the figure for the supine position. Henderson and Haggard[5] questioned earlier results because in the cases studied by them the change from the flat to the inverted position was accompanied by no marked effect upon either systolic or diastolic pressure. The pressures rose about as often as they fell, due probably to the slowing of the heart beat which accompanied the inversion of the body. Even in normal men, therefore, it is questionable whether a greater height of pressure is developed in the arteries when a head-down position is taken. At Béthune observations were made on the effects of raising the foot of the bed in cases of shock, but no benefit was noted as a result of the procedure. On the other hand, it proved to be rather disturbing to the patient. The failure of any benefit from tilting the bed is made rational by the facts which already have been presented. The method was based on the assumption that the stagnant blood was in the large veins of the abdomen. For gravity to be effective the blood would have to be chiefly in the vena cava, for there is no evidence that the blood of the portal vein can be made to pass through the liver capillaries by gravity drainage. All the evidence, both clinical and experimental, proves that the stagnant blood is not in the large veins. Consequently, the attempt to improve the circulation by postural change is naturally futile.

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VASOCONSTRICTOR DRUGS

For many years it has been the practice to attempt to improve the circulation in shock through the administration of adrenalin or pituitrin. Adrenalin constricts the arterioles in so far as they are effectively innervated by the sympathetic. Pituitrin acts by constriction of smooth muscle of the arterioles everywhere and has a more lasting effect than adrenalin. No doubt the arterial pressure may be temporarily raised by the intravenous exhibition of these drugs. The rise of pressure, however, results from increase of resistance in the tips of the arterial tree; in consequence, the blood accumulates more and more in the arteries because of the difficulty of exit. This accumulation will lead temporarily to a better flow through the heart muscle and the cerebral vessels when adrenalin is used, because in the presence of a high arterial pressure the arterioles of these regions are not constricted. The effect, however, is very temporary. When pituitrin is used there may be contraction of the smooth muscle of the cerebral as well as the cardiac vessels. However, the increased arterial pressure, when either of these drugs is employed, gives a wholly spurious impression of the state of the circulation. Damming the blood in the arterial portion of the circulatory system when the organism is suffering primarily from a diminished quantity of blood, obviously does not improve the volume flow in the capillaries; in other words, the desideratum is not merely a higher arterial pressure in the treatment of shock but a higher pressure which provides an increased nutritive flow through the capillaries all over the body. This improvement can be obtained when, as in shock, a diminished volume flow is the cause of the low pressure, only by increase of the volume flow. It can not be accomplished by medication. In the British and American armies the use of stimulant drugs, such as strychnine, and also vasoconstrictor drugs, such as pituitrin and adrenalin, practically disappeared during the course of the war.

A drug which has been advocated for shock cases, especially by French surgeons, is camphorated oil injected slowly into the circulation itself. The argument for this drug is that it promptly improves the action of the heart and thus permits time to be gained for the use of other measures. Here, again, we may apply critically the evidence obtained in clinical and experimental observations. It has shown that the heart is not primarily affected in shock. Unless the low pressure has persisted for a long time the action of the heart promptly becomes normal as soon as a sufficient volume flow of blood is present for it to act upon.

FORCED ABSORPTION OF FLUIDS

Experiments by Gesell [6] proved that a relatively small loss of blood greatly reduces the volume flow through peripheral organs. The converse also is true; when the circulation is failing from a low content of the vessels slight increase of blood volume will greatly increase the peripheral flow. This fact is the basis for treating low blood pressure by increasing the circulating fluid even though solutions incapable of conveying oxygen or carbon dioxide are employed for that purpose. As Gesell has pointed out, the nutrient flow may be increased several hundred per cent by injecting an inert solution—an increase

out of all proportion to the dilution of the blood produced by the added fluid. According to Rous and Wilson,[7] about 75 per cent of the total hemoglobin may safely be removed provided the bulk of circulating fluid is maintained.

The simplest means of increasing a reduced blood volume, if the condition of the patient is not urgent, is by giving fluids by mouth. Unfortunately, vomiting is likely to occur when shock is well developed. In that event, and in case the patient's condition will permit, the rectal route may be used. Robertson and Bock [8] proved that in case of reduced blood volume, fluid administered in large amounts by way of the alimentary tract is to a high degree retained in the circulation. By direct tests they showed that when patients who had suffered hemorrhage were treated by forcing fluid through the intestinal wall into the circulation the blood volume could be much increased. They gave water by mouth as rapidly as the patient would take it, and normal salt solution by rectum; after well marked hemorrhage 250 c. c. of normal salt solution could thus be given every half hour. By these procedures in one instance they increased the blood volume nearly 1,400 c. c. in 24 hours. As the volume became restored to near the normal the urine output became almost as large as the water intake. These observations on cases of hemorrhage are an indication of what may be done through simple measures in nonurgent cases of shock where there is a similar lack of circulating blood. The remarkable feature of the results of Robertson and Bock is the increased volume of fluid held in the blood vessels when water or salt solution enters the body by natural channels, which is very different from the effects of direct injection.

INJECTION OF SALT SOLUTIONS

All the evidence, clinical and experimental, indicates that the intravenous injection of warm normal salt or Ringer's solution has only a temporary effect. The injected fluid promptly passes from the capillaries into the tissue spaces and within a brief period the pressure is as low as before, if not lower.

Favorable results have been claimed for normal salt solution given subcutaneously, but not on the basis of critical observation. Both in human cases and in experimental animals with low blood pressure and sluggish blood flow, salt solution injected under the skin has been found post-mortem spread through the fascia in the region of injection. At Dijon, Robertson carefully followed the hemoglobin percentage after subcutaneous injection of salt solution in a shocked animal and found no dilution of the blood such as would appear if the solution entered or were retained in the vascular system.

Early in 1917 the injection of hypertonic salt solution was suggested as a way of withdrawing fluid from the tissues and increasing the blood volume by an "internal transfusion." Experience proved, however, that though the pressure could thus be raised the effect was transitory. No doubt the higher osmotic pressure of a concentrated solution does for a time attract water into the blood stream, but since the capillary wall is freely permeable to salts they are soon equally distributed and then nothing prevents a rapid infiltration of the injected fluid outwards into perivascular spaces.

Because of the strikingly favorable immediate results obtained by injecting sodium bicarbonate in shock cases which were characterized by marked

acidosis and "air hunger," Wright,[9] and later Cannon, Fraser, and Cowell,[10] suggested that such solutions be employed to raise the blood pressure and simultaneously to increase the low alkali reserve. Clinical experience proved, however, that usually by the time such extreme conditions have developed sensitive structures in the body have been so much injured that the beneficial effects are not likely to be permanent; and experimental analysis led to the conclusion that the reduced alkali reserve is the consequence of a low blood pressure and that it is probably not an important secondary factor in augmenting shock. Since "acidosis" in shock indicates a deficient delivery of oxygen to active tissues, the rational move is not to treat the effects, but the cause, i. e., to provide for a better supply of oxygen by early and permanent improvement of the circulation. As the foregoing paragraphs show, salt solutions alone are incapable of achieving this result.

GUM-SALT SOLUTION

Salt solutions fail to produce a permanent rise of blood pressure because they lack a colloidal material which, like the protein of the blood plasma, will not pass through the capillary walls and which, by its osmotic pressure, prevents water from passing through. Various colloids have been suggested to compensate for this lack, among them being boiled starch, agar, dextrin, gelatin, and gum acacia. Bayliss [11] carefully analyzed the properties of these substances and found that gum acacia alone is free from serious objections and capable of replacing blood plasma. A solution of 6 to 7 per cent of it in 0.9 per cent sodium chloride has the same viscosity as whole blood and the same osmotic pressure as blood plasma. It is chemically inert; it does not cause thrombosis or promote clotting; it can be sterilized without chemical or physical alteration; and it does not induce anaphylactic reactions when repeatedly injected. Only the purest pearls are to be used. They should be placed in tap water or freshly distilled water and allowed to swell for a day. They may then be dissolved quickly over a water bath. The solution must be filtered finally through paper of coarse texture. Bayliss showed experimentally that "gum-salt" solution will restore permanently a low blood pressure produced by removal of 40 per cent of the estimated blood volume. Meek and Gasser [12] reported injecting gum until it was 10 per cent of the blood without ill effects. And Drummond and Taylor,[13] after an experience with it in 38 cases, and McNee,[14] after an experience in more than 100 cases, declared it harmless for man.

Though reports highly favorable to the use of gum-salt solution have been made, strong opinions have been expressed against its use. Mixter [15] cited two cases in which death, in his opinion, was caused or hastened by gum-salt injection, and Lee,[16] though reporting an excellent result from its use, mentioned two cases of collapse. The writer has earnestly endeavored to obtain reliable data showing under what conditions the solution is useless or harmful. In October, 1918, at his suggestion. Maj. O. H. Robertson visited the forward hospitals in the American area and systematically collected observations and opinions from a large number of resuscitation teams. Along with laudatory

statements there were some that were indifferent and others condemnatory. According to Robertson's [17] analysis, the unsatisfactory results occurred in cases of long-lasting shock (15 to 20 hours), cases treated before being warmed, cases of very severe hemorrhage, and cases of gas bacillus infection. These conclusions coincide with those of Ohler,[18] who had large experience as a resuscitation officer.

In both the British and American Armies gum-salt solution, when used early in cases of shock and moderate hemorrhage, had excellent effects which brought forth enthusiastic commendation from good clinical observers. These results were comparable with those obtained under experimental conditions on lower animals. But during September and October, 1918, when the wounded were brought in after prolonged exposure to cold and wet, the favorable action of the solution, that had been noted in July and August when the weather was warm and the transportation prompt, were no longer observed. American medical officers reported that they tried it then and obtained no benefits from it. Under the hard conditions of the autumn, however, it was found that blood transfusion also was often quite as ineffective as the artificial fluid in restoring the circulation. British experience was summarized in a statement issued after a conference of British surgeons (including Maj. Gen. Sir Anthony Bowlby, Maj. Gen. Sir Cuthbert Wallace, Col. S. L. Cummins, Col. T. R. Elliot, Maj. J. W. McNee, Maj. Geoffrey Marshall, and Capt. N. M. Keith) held in November, 1918. They agreed that when made from pure pearls of acacia and introduced warm and at a slow rate, gum-salt solution had no seriously harmful effects; that it has a valuable place in resuscitation; but that in order to have beneficial action it must be given early.

The writer occasionally has seen "chills" follow its use in cases near death from shock, but a similar reaction occurs, at times, after the intravenous injection of blood or normal salt solution. In this connection the recent discovery of Stokes and Busman [19] is important. They found that just such reactions as have been ascribed to gum-salt—chills, sweating, and subsequent prostration—are due to a toxic agent present in rubber tubing used for intravenous injection. This factor should be ruled out before evil action is attributed to the gum-salt solution itself. De Kruif [20] subjected gum-salt solution to very thorough tests as to its toxicity, with negative results. All the experimental testimony indicates that the properly prepared solution is innocuous.

Various reports mentioned above emphasize the importance of early treatment of low blood pressure. Reasons for this have already been mentioned in relation to the damage done to nerve cells when long subjected to oxygen lack. In addition there is likely to be, as a consequence of defective blood supply, and of the action of toxic agents, an increasing permeability of the capillaries. Keith [21] reported two cases in which 1,000 c. c. of gum-salt solution were injected, but without beneficial effect. In one case determination of the blood volume before and one hour after the injection (shortly before death) showed that the addition of 1,000 c. c. had increased the blood volume only 200 c. c. In the other case gum-salt solution was given after the blood had concentrated so that the hemoglobin percentage had risen from 104 to 120. The injection

caused no improvement, and at autopsy the lungs and subcutaneous tissues were edematous. Similar instances have been reported to the writer by resuscitation officers in the American Army. The conclusion drawn by Keith was that in the late stages of shock the capillaries may become so damaged that they are no longer capable of retaining fluid, even though it be a colloidal solution. These observations and the interference from them fit closely the conception that in shock the reduction of blood volume is due to escape of plasma, because of increased capillary permeability.

HYPERTONIC GUM ACACIA AND GLUCOSE

Erlanger and Gasser [22] produced shock experimentally by a standard procedure—holding the arterial pressure down to 40 mm. Hg. for two and a quarter hours. They then treated the animals by giving 25 per cent gum in 18 per cent glucose. The virtues of this hypertonic solution they believed to be (*a*) the drawing of fluid from the tissues into the blood stream and thus the increasing of blood volume; (*b*) the maintenance of the increased volume through some property of the gum acacia; (*c*) the dilatation of the arterioles through a specific action of the hypertonic glucose; (*d*) the increase of the energy and food supply of the heart; and (*e*) the augmentation of metabolism. When animals subjected to standard shock-producing trauma were left untreated (23 cases) 48 per cent died within 48 hours. When they were treated (21 cases) by injecting intravenously the hypertonic solution at the rate of 5 c. c. per kilogram per hour only 24 per cent died within 48 hours.

There is some question whether in this particular feature results obtained on the shocked dog can justifiably be transferred directly to man. For example, the dog does not absolutely lose fluid from the body by sweating as man does; it is probably present in the tissues or lymph spaces. On the other hand, in wounded men, according to Robertson and Bock,[8] blood volume is made up very slowly; often after five or six days these cases have less than two-thirds of the normal. The indications seem to point, therefore, to the need of adding fluid to the body rather than attempting to withdraw fluid from tissues which may themselves be lacking it. Erlanger and Gasser have tested the method of Robertson and Bock, however, on shock-like states in man (12 cases), and they found that the solution was not only innocuous but produced results "strongly suggestive, to say the least, of beneficial action." [22] The only ill effects which they observed occurred under experimental conditions when the hypertonic gum solution was run rapidly into the veins of dogs almost moribund; then the heart became irregular and stopped as though it had passed into fibrillation. After an experience with over 200 animals they state: "If there is any one thing we are convinced of, it is that gum acacia when given slowly is entirely innocuous." [22]

Full knowledge of the merits and limitations of gum-salt solution under clinical conditions may be regarded as not yet attained—except in late shock, when it has proved useless. After severe, induced hemorrhage and in experimental shock caused by muscle injury, gum-salt solution has been shown to be capable of raising and maintaining a normal blood pressure. Its service

under these circumstances lies in speeding the circulation and thus inducing a greater use of the red corpuscles for the delivery of oxygen to the needy tissues. At best, however, it is a substitute for blood.

TRANSFUSION OF BLOOD

The transfusion of compatible blood in cases of persistently low arterial pressure has been proved beyond question to be highly valuable by experience during the war. Blood can permanently raise arterial pressure, as gum-salt solution can; but in addition it contributes to the recipient a large increase of oxygen-carriers—the red corpuscles. Theoretically, however, in pure shock, when plasma has escaped and corpuscles are crowded in capillaries, gum-salt solution should be quite as good as blood, if not preferable to it; and even after hemorrhage, when not severe, it should serve well. In a series of carefully observed cases, Keith [21] found that the results of intravenous injection of gum-salt solution and whole blood were practically identical. He concluded that probably in some cases of shock blood transfusion would give better results than the solution, but such cases did not come under his observations. On the other hand, Robertson and Bock [8] and Lee [23] declare that when the hemorrhage factor is large in the production of circulatory deficiency blood is highly preferable to any indifferent fluid. Ohler [18] is of the same opinion, and he cites cases in which, after gum-salt solution had failed to sustain arterial pressure, transfusion of blood was successful. That this was not due merely to an additive effect of introducing more fluid is indicated by the gradual fall of pressure to the former low level in these cases after the gum-salt injections and the satisfactory rise after transfusion. It seems probable that what Pike and Coombs [24] suggested regarding nerve cells is true generally throughout the body—that "injured cells require a better blood supply for their restoration than uninjured cells do for mere maintenance." At least, in the experience of many men who had great opportunities for observation during the war, blood transfusion was found to be the most effective means of dealing with cases of continued low blood pressure, whether due to hemorrhage or shock.

There is the same urgency for using blood early, before serious damage has been done, as there is for using any substitute for blood. Keith [21] reported cases of failure of blood transfusion in which there was evidence of escape of fluid, just as there was in his failures with gum-salt solution. In one instance 880 c. c. of whole blood increased the recipient's blood volume only 150 c. c. At autopsy in this and in another similar instance edema of the lungs and more than normally moist tissues were found. To be effective, therefore, blood must be introduced before a low nutrient flow has caused irreparable injury.

As the methods of matching blood, the technique of transfer, and the absence of harm to donors become better known, blood transfusion seems certain to become the method of choice for restoring a low blood volume. In hospitals the personnel may be classified in blood groups for emergency purposes. And in military service it is desirable that the lightly wounded and the gassed cases be sent near the shock wards, so that blood may be obtained promptly for those who are in sore need of it.

Method Employed in the American Expeditionary Forces[b]

In March, 1918, a committee representing the laboratory and surgical services of the United States Army adopted transfusion with citrated blood as the method for combating shock and hemorrhage in the hospitals of the American Expeditionary Forces. The reasons for this choice were simplicity of equipment and technique, convenience to donor and recipient, and excellence of results. The chief precaution to be regarded is the quick delivery of the blood through clean tubes into the citrate solution, so that changes in the blood in the direction of coagulation may be arrested as soon as possible.

The only apparatus required for this method is a liter bottle provided with two rubber stoppers having two perforations, appropriate glass and rubber tubing, and two transfusion needles. (See figs. 106 and 107.) The largest size needle is used for bleeding, the small size for giving the blood. The rubber tube B should be short and of large bore to assure a rapid flow and lessen the chance of coagulation. A convenient suction and pressure pump may be made from an ordinary Davidson syringe. Suction or pressure can be made by reversing the ends.

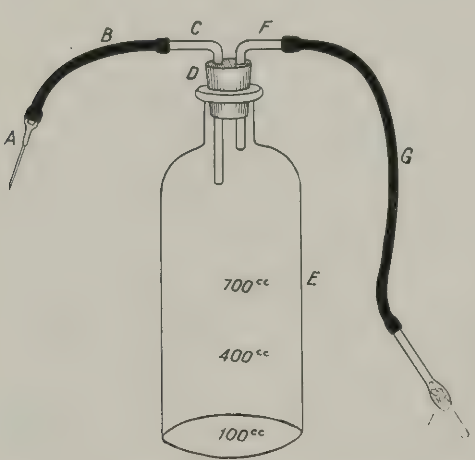

Fig. 106.—Transfusion apparatus. *A*, Transfusion needle *B*, rubber tube; *C*, glass tube; *D*, rubber stopper; *E*, bottle of liter capacity; *F*, glass tube; *G*, rubber tube; *H*, glass tube for suction, with cotton in bulb

The bottle E and the stoppers and tubing are wrapped in a towel and sterilized in an autoclave. Prepared in this way, the apparatus may be kept sterile and ready for immediate use. If an autoclave is not available the apparatus should be sterilized by boiling in previously boiled or in distilled water.

The needles are sterilized by boiling just before the transfusion. If they are being repeatedly used they may be sterilized in boiling liquid petrolatum or albolene and left standing in the oil until needed. The needle is the most important part of the apparatus and requires careful attention. Before each bleeding it should be well sharpened. The chief consideration in the sharpening is to produce a fine spear point with a bayonet edge. This is best done by grinding first on the bevel—which should be moderately short—and then on the back of each edge at the point. If the point is well protected when not in use sharpening will require only a few moments. Before boiling, the needle should be slipped into a short length of rubber tubing. The needle must be kept scrupulously clean. After each bleeding it should be washed out at once, all fragments of fibrin or clot removed from the base, and small pieces of cotton soaked in oil thrust through the lumen with the stilette. The whole needle should be well oiled before being put away.

[b] The present description is taken largely from "A Report upon the Transfusion of Blood for the Recently Injured in the United States Army," published by the Medical Division of the American Red Cross Society in France 4, Place de la Concorde, Paris, May ,1918.

Before the blood is collected a tube of sodium citrate is broken off at the file mark, the opened end flamed, and the contents poured into the bottle E. Normal saline solution (0.9 o/o) is then added up to 100 c. c., (i. e., to the *top* of the figure). When the bottle is filled to 700 c. c. the citrate present is 0.6 per cent. The apparatus (see fig. 107) is then assembled so that the rubber stopper fits snugly into the mouth of the bottle. Great care should be taken to keep all the open parts sterile.

Bleeding.—The donor's arm is now extended at a right angle to the body. A tourniquet is applied to the arm high up—the cuff of a blood-pressure apparatus folded to half its width makes an excellent tourniquet with the pressure kept at 50–60 mm. of Hg. Choose a suitable vein in the bend of the elbow, remembering that the needle is best inserted toward the hand. It is important to have as large a vein as possible. Opening and closing the fist and flicking the skin over the veins cause them to dilate considerably. The tourniquet is then released. The skin over the vein is scrubbed with soap and water and the sterilization completed with alcohol. At the point selected for venepuncture a small quantity of novocaine or cocaine is injected intracutaneously. A very slight nick is then made through the skin with the point of a scalpel. The tourniquet is tightened and the means above described are again employed to dilate the vein. Do not touch the point of puncture. The bottle is placed on a stand close to the patient's arm in such a position that there will be no kinking of the tube B when the needle is in the vein. After drying the skin opening with a piece of sterile gauze the needle is inserted for a short distance beneath the skin; then by raising the base slightly it is pushed into the vein. It is essential to keep the needle immobile. The operator should hold it throughout the bleeding, steadying his hand against the donor's arm. With the free hand the bottle is given a rotary motion every few seconds in order to insure thorough mixing of the blood with the citrate, which is very important. A moderate degree of suction is maintained either by means of the tube H, which is held in the operator's mouth, or more conveniently by using the adapted syringe pump. The donor continues to open and close his hand slowly, making a firm fist each time, care being taken that he does not move his arm.

The citrated blood does not coagulate and consequently its introduction into the recipient need not be hurried. Under ordinary conditions the blood will be used immediately, but when occasion requires it may be kept for several hours before introduction. If in the course of drawing the blood clotting occurs and the blood ceases to flow, release the tourniquet, withdraw the needle, and obtain the blood through use of entirely fresh apparatus (needle, rubber, and glass tubing), which should be at hand, sterilized for such an emergency. It is usually better to take the other arm.

Six hundred c. c. of blood is the limit to be removed, for a donor may lose this amount without distress. If more blood is required a second donor must be taken. The same donor must not be used twice within a single week.

The bottle of blood should be placed in a receptacle containing water at about body temperature, where it should be kept during the transfusion.

Transfusion.—The introduction of the blood into the recipient is accomplished by removing the first stopper D (fig. 106) with its connections and putting

the stopper N (fig. 107) with its connections snugly into the mouth of the bottle. Air pressure is increased by blowing through the tube Q, and blood begins to rise in the tube M, which forms one limb of the siphon K, L, M (fig. 107). The tube K is held high as the blood passes into the rubber tube L and then is gradually lowered. When K is completely filled a pinchcock closes the rubber tube L close to the glass tube K.

A bandage or tourniquet is placed about the arm of the recipient sufficiently tight to give the maximum venous pressure. Remember that the arterial pressure of the recipient is low; the arterial flow must continue if the veins are to be made prominent. The needle I with the short rubber tube J attached is then introduced, in the direction of the venous stream, into the vein of the recipient. As the blood begins to flow through the needle and tube the assistant quickly removes the bandage while the operator immediately connects the rubber tube J with the glass tube K, the precaution being observed to have both tubes filled with blood. The bottle is then raised to the full height allowed by the rubber tube L, the pinchcock is opened, and the blood enters the recipient by gravity. The time allowed for the introduction of 600 c. c. of blood should not be less than 10 to 15 minutes. Any symptoms of distress should indicate a checking of the flow. Such symptoms, which are usually nothing more than a feeling of fullness and slight respiration difficulty, are ordinarily transient. At the completion of the transfusion a small amount of blood will remain in the bottle below the level of the glass tube M.

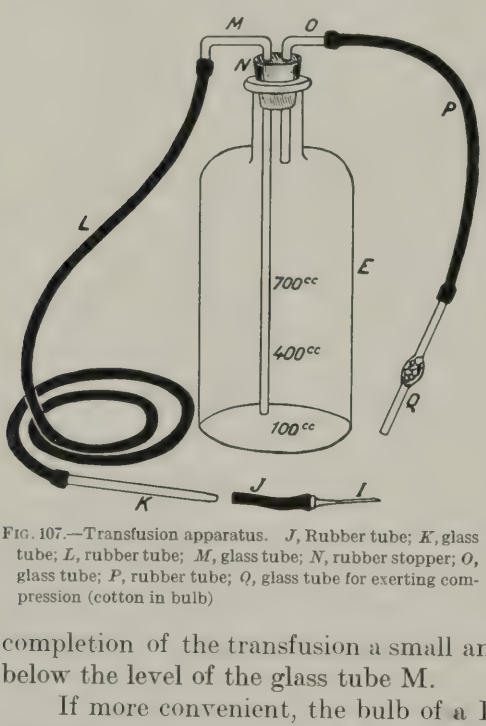

Fig. 107.—Transfusion apparatus. *J*, Rubber tube; *K*, glass tube; *L*, rubber tube; *M*, glass tube; *N*, rubber stopper; *O*, glass tube; *P*, rubber tube; *Q*, glass tube for exerting compression (cotton in bulb)

If more convenient, the bulb of a Davidson syringe or of a blood-pressure apparatus may be connected with tube P (fig. 107), and the blood forced in by air pressure.

If the veins of the recipient are very small or collapsed an incision may be made and a canula introduced into the vein.

After use the apparatus must be cleansed with cold water immediately. If not being frequently used the needles should thereupon be dried by running first alcohol and then ether through them, after which they should be stored in test tubes with a cotton plug in the bottom and the mouth of the tube. The needles must be kept sharpened.

Selection of donors.—There exist in the plasma of animals certain bodies which will agglutinate or agglutinate and hemolyse the red blood cells of other individuals who are members of the same species. The transfusion of such incompatible blood may be fatal to the recipient. Among human beings it is definitely

known that all individuals fall into one of four groups. Knowledge of these groups has proved of practical value in blood transfusion. Hemolysis does not take place between individuals belonging to the same blood group, and practically never takes place between certain definite combinations of different groups. Having determined the blood group, it is possible to select a donor whose blood is compatible, as regards hemolysis, with the blood of the recipient.

The classification of these groups is as follows:

Group I. Serum agglutinates no corpuscles. Corpuscles agglutinated by sera of Groups II, III, and IV.

Group II. Serum agglutinates corpuscles of Groups I and III. Corpuscles agglutinated by sera of Groups III and IV.

Group III. Serum agglutinates corpuscles of Groups I and II. Corpuscles agglutinated by sera of Groups II and IV.

Group IV. Serum agglutinates corpuscles of Groups I, II, and III. Corpuscles are not agglutinated by any serum.

The incidence of the four groups is approximately:

Group I, 5 per cent; Group II, 40 per cent; Group III, 10 per cent; Group IV, 45 per cent.

The following table shows the relation of the four blood groups with respect to agglutination of corpuscles:

Corpuscles	Serum			
	I	II	III	IV
I	0	+	+	+
II	0	0	+	+
III	0	+	0	+
IV	0	0	0	0

(+=agglutination; 0=no agglutination.)

In order to determine the group of an individual, it is sufficient to test his corpuscles against known sera of Groups II and III. This is readily accomplished by a macroscopic test, which in addition to the two known sera requires only a glass slide, a needle, and two small glass rods. Citrated sera for this test are furnished by the Central Medical Department Laboratory. These sera remain active indefinitely, as a rule, but they should be tested occasionally against blood of known groups to prove that they are active and ready for emergency.

The test is performed as follows:

By means of the stopper in the bottle place a drop of Group II serum on the left half of the glass slide (slide need not be sterile, but should be clean and dry) and a drop of Group III serum on the right half of the slide.

Puncture the ear or finger of the individual to be tested, and transfer in turn to each of the sera about one-third of a drop of blood, on the end of the glass rod, mixing the blood intimately with the serum. Avoid mixing too much blood with the serum; it will prevent a clear result. Take care to transfer the blood before coagulation has commenced. Avoid mixing the two

sera; a separate glass rod or opposite end of a rod must be used for each transfer. Agitation of the slide accelerates the appearance of an agglutination.

Within a few seconds after mixing the blood and sera one may see a brick-dust-like appearance in one or both sera, or one may see only a homogeneous suspension of the cells in one or both sera. If the distinction between the

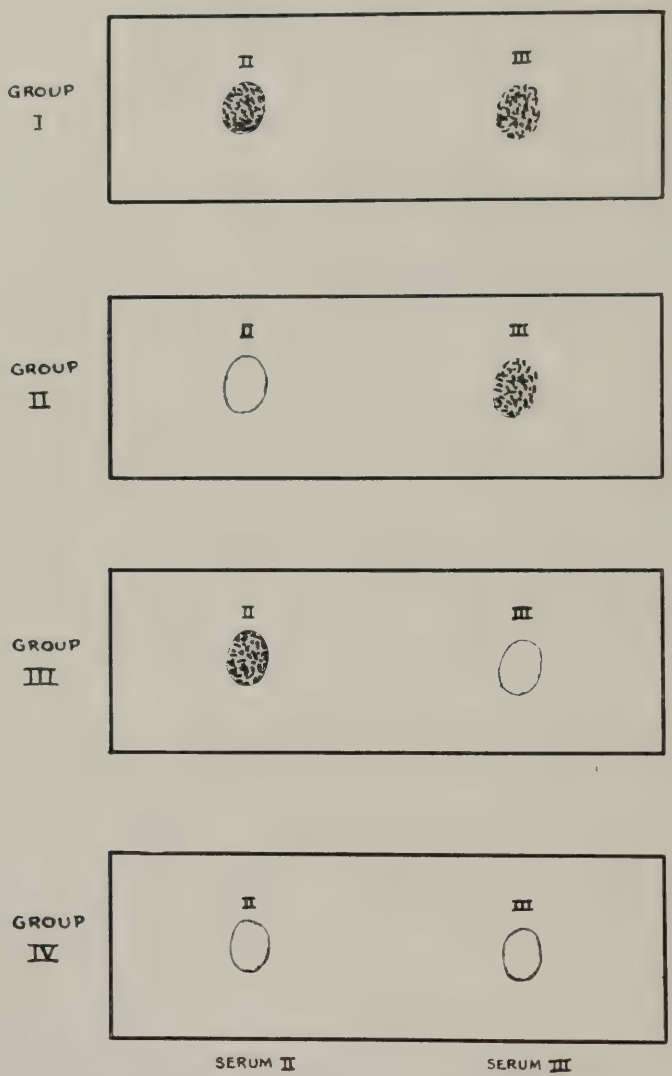

FIG. 108.—Graphic illustration of macroscopic agglutination test

"brick-dust" and the homogeneous appearance should not be quite clear, tip the slide toward the vertical; a thin layer of blood will be left in the upper limits of the drop in which the difference, if present, will be evident. The brick-dust-like appearance denotes agglutination. Occasionally there is a tendency to rouleaux formation, which may be confusing. Rouleaux formation appears more slowly than agglutination, and, contrary to agglutination, is

dissipated if the rouleaux are broken up by stirring the serum. In the rare instances in which the agglutination is questionable, the donor should not be used.

Groups are indicated as follows:

When agglutination occurs in both sera the individual belongs to Group I.

When agglutination occurs only in III serum the individual belongs to Group II.

When agglutination occurs only in II serum the individual belongs to Group III.

When no agglutination occurs in either serum the individual belongs to Group IV.

Except in cases where the risk of delay is greater than the risk of hemolysis, the compatibility of the blood of donor and recipient should be determined before transfusion. It is not necessary that the donor belong to the same group as the recipient. The only practical consideration is that the recipient does not agglutinate the red corpuscles of the donor. From the above table it is seen that the red cells of Group IV are not agglutinated by the serum of any other group. Therefore, in practice it is simpler, whenever possible, to use only donors of Group IV, in which case the patient's blood does not require testing. Group I recipients can take donors of any group, since the serum of Group I agglutinates the cells of no other group. Recipients of the other groups can take donors of their own group or Group IV only.

No person should be used for a donor who has, or has had, syphilis, malaria, trench fever, or who has recently recovered from other infectious diseases.

Lightly gassed patients, i. e., patients whose color is normal or nearly normal, may be used as donors if properly grouped and free from transmittable disease.

Patients with scabies may be used as a source of blood for transfusion if they are otherwise satisfactory.

In general, convalescent patients who are nonfebrile and in good physical condition constitute the class from which donors may be selected.

No reward is to be offered a donor; his consent must be obtained without urging or compulsion.

A list of donors, with their group, age, ward, and bed, must be posted in the operation room and in the resuscitation ward. When necessity arises, a donor is thus immediately obtainable. To avoid a possibility of error this list should provide every means for proper identification. For absolute assurance, small perforated metal tags should be provided, marked to indicate the group to which the man belongs. This tag must be attached to the man by the individual making the test at the time the grouping is determined.

Transfusion Equipment For A Hospital

A. APPARATUS

1. Plain glass bottles of 1 litre capacity, marked 100 c. c., 400 c. c. and 700 c. c. at the proper levels	4
2. Rubber stoppers to fit the bottle (2 perforations)	6
3. Glass tubing. The glass tubing has a total diameter of 5 mm., thickness of wall 1 mm.; opening 3 mm. (for identification see interpretation of Figures I and II).[a]	
C. Long right angle tubes, one arm 10 cm. long, the other 6 cm. long	3
F. O. } Short right angle tubes, each arm 6 cm. long	6
H. Q. } Tube for suction or compression (dilated in center for reception of small bit of cotton), 1 cm. long	4
K. Straight tubes, narrow at the top, 10 cm. long	2
M. U tube, short arm 4 cm. in length, long arm 25 cm. in length	3
4. Rubber tubing. The rubber tubing has a total diameter of 6½ mm., thickness of wall 1½ mm., opening 3 mm.	
B. Short tubing for collection needle, 12 cm. long	3
G. P. } Tubing for suction or compression 30 cm. long	3
J. Short tubing for introduction needle, 7 cm. long	3
L. Long tubing for introduction apparatus, 1 meter 30 c. long	2
5. Transfusion needles. These are made of steel. The total length of each needle is 4 cm.; the length of the shaft is 2½ cm.; the length of the point is 4 mm., the length of the base is 1½ cm. with a flat portion on two opposite sides. The size of the needles and the number required are: 25/10 mm., 2; 20/10 mm., 2; 16/10 mm., 2; 13/10 mm., 2.	
6. Stone for sharpening needles	1
7. Small infusion cannulæ. The total length of the cannulæ is 39 mm.; the length of the tip is 2 mm. and there is a small collar at the base of the tip, giving a diameter 1 mm. larger than that of the shaft; the length of the tip and shaft together is 33 mm.; the length of the base is 6 mm.; the sizes of the cannulæ are: one of 20/10 mm., the other 30/10 mm.	2
8. Pinchcock	1
9. Test tubes for needles	12
10. Small test tubes for cannulæ	3
11. Paraffin 54° C. ....kilo	1
12. Emery paper small sheets	10
13. Wooden box, well made and finished, to carry above apparatus, labeled: "Transfusion, Medical Dept., U. S. Army."	

B. LABORATORY TRANSFUSION SUPPLIES

1. Bottles of Group II and Group III sera, labeled as below:

Serum II		*Serum III*	
Sodium citrate	1. 5	Sodium citrate	1. 5
Tricresol	. 25	Tricresol	. 25
Date.		Date.	

[a] Figures 106 and 107.

1 bottle of each serum

2. Sterile sealed tubes of sodium citrate solution with file mark for breaking point, labeled: "Sodium citrate in 0.9 saline, quantity sufficient to citrate 600 c. c. of blood to 0.6 per cent: date ______"_______tubes__ 48
3. Glass slides with II and III marked into the glass, in the upper left and right hand corner respectively__________ 12
4. Small tube containing small glass rods__________ 12
5. Small bottle of alcohol for care of needles__________ 12
6. Small bottle of ether for care of needles__________ 12
7. Bottle of blood counting fluid__________ 12
8. Small metal tags (perforated) stamped to indicate the group of the patient:
   - Blood Group I__________ 10
   - Blood Goup II__________ 100
   - Blood Group III__________ 20
   - Blood Group IV__________ 100
9. Small ball of twine for fastening tag to the individual groups.
10. Wooden box, well made and finished, to carry the above supplies, labeled: "Laboratory supplies. Transfusion, Medical Department, U. S. Army."

Precautions to be observed in intravenous injections.—Whether blood or an indifferent fluid is injected, careful attention should be given to the mode of procedure. The possibility of further loss of blood, as the pressure is raised, should be eliminated. The fluid should be introduced slowly and with little pressure. Zunz and Govaerts[25] showed that blood transfusion after hemorrhage is effective in restoring normal blood pressure when 40 to 75 minutes are taken to replace about half the blood volume. But if this amount is introduced in 5 to 10 minutes a marked fall results which may last for hours. And they noted that the deeper and more lasting the circulatory failure before the transfusion the more slowly must the blood be injected in order to avoid a subsequent drop of pressure.

The fluid should be given warmed to body temperature, or, better, slightly above, in order to enter the body warm after passing through the connecting tubes.

If any harmful or unfavorable effects are noticed as the fluid is entering the blood stream, the flow should be checked at once. The amount injected usually need not be great; 500 or 750 c. c. may be given at first, and later 500 c. c. more if circumstances seem to require it. This probably will not restore the blood volume to normal, for, as Keith[21] and Robertson and Bock[8] showed, the volume is often reduced as much as 2,000 c. c. or more. Therefore, though an intravenous injection may raise the pressure satisfactorily, other and simpler means of increasing the circulating fluid should be continued—such as fluid by mouth and rectum.

On the basis of their Béthune experience in 1917, Cannon, Fraser and Hooper[26] called attention to the unfavorable prognosis attending continued concentration of the peripheral blood, and to the disappearance or "dilution" of the blood as recovery occurs. Both Keith[21] and Lee[23] emphasized the significance of these blood changes, and suggested repeated hemoglobin determinations in order to learn whether "dilution" is occurring and whether the patient, therefore, is on the course toward improvement and recovery.

OPERATION

Operation on a man who has been greatly injured, or who is in shock, or who has been in shock for a considerable period and has to some degree recovered, is likely to be hazardous because blood pressure barely sustained, or already low, or only recently restored, may be reduced seriously by operative procedures. A number of conditions contribute to this danger, some of which can be avoided.

Anesthesia

The fall of blood pressure during or after operation in shock is probably due chiefly to ether or chloroform anesthesia. Sharply contrasted with the effects of these general anesthetics in shock cases is the action of nitrous oxide and oxygen or "gas-oxygen." During his extensive experience as an anesthetist in a casualty clearing station in Flanders, Marshall [4] found in a large series of very severe cases that gas-oxygen anesthesia was followed by no increase of shock whatever. And Bazett,[27] who likewise had abundant opportunities to make careful observations, has testified: "One can only say that with nitrous oxide and oxygen anesthesia there is rarely any sign of shock observed. The clinical contrast between cases anesthetized with nitrous oxide and oxygen and those receiving other general anesthetics is enormously in favor of the former." In this connection Dale's observation [28] on the relation of ether and gas-oxygen to histamine shock are highly pertinent. He found 10 mg. of histamine per kilogram necessary to produce shock in the unanesthetized animal, whereas under ether 1 to 2 mg. were sufficient. But under gas-oxygen shock would be induced only by giving the dosage required in the unanesthetized state, i. e., 10 mg. Ether and the toxic agent cooperated to bring on the low pressure; with gas-oxygen anesthesia the cooperation was lacking. Bazett [27] noted that after ether or chloroform there was a concentration of the blood, amounting at times to 20 per cent. With rapid operation under gas-oxygen, however, very slight and only temporary concentration was seen.

Gas-oxygen should be given with great care and by experts in its use. Cattell [29] noted that high ratios of nitrous oxide to oxygen are quite as harmful as ether. A ratio of three parts nitrous oxide to one of oxygen caused no fall of blood pressure whatever. Gwathmey and Yates [30] found in their work on chest cases in battle areas that with a preoperative use of morphine, deep analgesia could be induced and maintained without increasing the ratio above three to one; Gwathmey [31] stated that, with proper preliminary medication, complete relaxation of the patient for prolonged periods is easily maintained under gas-oxygen anesthesia. American and British experience during the war led to strong affirmation that in shock cases gas-oxygen is undoubtedly the anesthetic of choice, and this conclusion was accepted by the Interallied Surgical Congress at Paris in 1917.[32]

Whatever the general anesthetic employed, there should be avoidance of deep anesthesia and cyanosis. With the blood volume reduced and the nutrient flow inadequate or bordering on inadequacy, the organism is in danger from oxygen want. Shutting down the oxygen supply is certain to do harm. As Marshall [33] remarked, cyanosis during operation causes a shocked man to lose ground which may be extremely hard to recover.

An alternative to general anesthesia, particularly in operations on the lower extremities, is spinal anesthesia. There is the possibility that through the blocking of tonic vasoconstrictor impulses in the spinal nerves a fall of blood pressure may result. Indeed, according to Quenu,[34] this is to be expected. The suggestion has been made that under such circumstances the pressure may be maintained by slow and continuous infusion of a weak solution of adrenalin. Theoretically this is an appropriate mode of procedure, but it is questionable whether there is a special advantage in its use.

Time of Operation

In 1917 Santy [35] observed 340 cases of nontransportable wounded, in 79 of whom the time between the reception of the wound and the surgical treatment was known. The mortality in these wounded was as follows:

Hours intervening	Number of cases	Mortality
		Per cent
1	10	10
2	9	11
3	8	12
4	11	33
5	9	36
6	12	41
8	8	75
9–10	12	75

As the above figures show, the mortality was only 11 per cent in the first three hours; it rose to 37 per cent when there was a delay of between three and six hours (though infection was not marked until after six hours); it was 75 per cent in the eighth to the tenth hour. Although during the first hour the cases were not in complete shock, they were in grave condition, anemic and cold. A review of Santy's full description of his cases reveals that in all there were wounds of similar severity. For example, the lesions in the group operated on in the first hour included (1) mashing and pulping of the arm and leg; (2) of the leg and knee and of the forearm (in a diabetic); (3) of the right thigh and left leg; (4) of the thigh in the lower third; (5) of the mid-thigh, with laceration of the muscle above; (6) of the leg above the right knee, with tearing away of the calf; (7) of the elbow, with wounds of the face, loss of an eye, and two large wounds of the thigh; (8) double shattering of the left arm and forearm; (9) destruction of the popliteal space with section of the artery; (10) laceration of the muscles of both thighs and the calf. Of these 10 cases 1 died. Amputation was performed in 7 cases; in 2 cases double amputation. Six of the 7 amputations resulted successfully. In the last group, operated upon after nine or ten hours, the lesions were: (1) Extensive laceration of both thighs; (2) smashing of the knee with muscular lesions; (3) crushing of the shoulder; (4) wounds of both thighs with section of the left femoral artery and vein; (5) shattering of the right knee; (6) multiple wounds of the thighs; (7) fracture of the right thigh and the left leg; (8) tearing away of the left arm; (9) muscular destruction of the right thigh; (10) smashing of the leg; (11) of

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both legs; (12) of the right thigh. Of these 12 cases, 9 died. There were 6 amputations with only 2 successes.

Santy's observations are sustained by Gatellier[36], who treated 13 serious cases, without waiting, by limited excision of injured tissues or by amputation, and had no deaths.

The excellent results of prompt operation, performed on the severely wounded before the development of secondary shock, have been noted before this time. The great French military surgeon, Larrey[37], who followed Napoleon's campaigns, laid down the dictum that crushing wounds of the extremities should be operated upon at once, for that treatment gives the only hope. The figures given by Santy point to action of some agency, which, as time passes, brings on the state of shock and seriously jeopardizes the chances of recovery. The bearing of these observations on the toxic origin of secondary shock is obvious. The crushed and lacerated tissues become not only a source of danger to the body from processes of death taking place in them but they are most favorable sites for infection. Therefore, for both reasons, early clearing away of destroyed tissue, or débridement, is a prophylaxis against shock and other damaging conditions. If secondary shock is existent when the patient, cold and depressed, is brought under surgical care, there is general agreement that simple measures, such as warmth, rest, and fluids, should be applied in an attempt to improve his state before operative interference is begun. If, however, there is continued hemorrhage accompanying and augmenting the shock, or if there is rapidly spreading infection (e. g., with gas bacilli), operation may be necessary before full recovery has occurred. And if the surgeon must begin his work thus, a protective transfusion of blood before the anesthetization, or while the wounds are being attended to, will keep the blood flow adequate during the most critical time.

The principle involved in the operative treatment of fully developed secondary shock is the same as that employed for prophylaxis against its development. As soon as possible there must be suppression of the trauma. This procedure is often the initial step in an extraordinary improvement in the patient's state. At the Interallied Surgical Conference, in 1917, Tuffier[38] declared that we have too long submitted to the doctrine that shock absolutely contraindicates operation. Experience proves that the exclusion of the focus of injury, by short and radical procedures, causes the symptoms of shock to disappear. And the conference concluded: "If true shock, without hemorrhage, is severe, if the patient is cold and pulseless, the shock itself must be treated first. It is the same if the operation to be done must be long and difficult. But extensive destruction of parts necessitating amputation indicates operative attack."

Quénu's advice is that in any case, long and complicated operation should be avoided; meticulous surgery is out of place; the principal lesion must be treated quickly and radically, and often less important wounds can be given only simple cleaning.

Precautions to be Observed During Operations

The relation of cold to shock has been repeatedly emphasized. During operation every effort previously employed to prevent heat loss should be continued; needless exposure of the body should be avoided. The skin and protective coverings should not be allowed to remain wet, for both by evaporation and by more rapid conduction the escape of heat from the body thereby is promoted. Cavities and wounds should be washed out with warm solutions only. The operating room and the operating table should be warm; even under the rudest circumstances simple arrangements can be made for these desirable conditions.

In the foregoing pages emphasis has been placed upon the sensitiveness of the badly injured and the shocked to hemorrhage. A small loss of blood, wholly without permanent effect under ordinary circumstances, may cause a calamitous fall of pressure. Special care should be exercised during operation on shock cases not to lose a drop more blood than actually must be lost.

Marshall[4] called attention to the fact that after larapotomy on a man who is or has been in shock, a turn of the body laterally causes a sharp drop in blood pressure. He urged that if the back as well as the abdomen has been wounded, it be dealt with before opening the abdomen. Binders or many-tailed bandages should be applied by lifting the body, not by turning it free from side to side.

Abdominal and thoracic viscera should not be exposed or pulled upon more than is absolutely required for the satisfactory performance of the operation. And all tissues should be handled with extreme gentleness.

TREATMENT OF PRIMARY SHOCK

The occurrence of primary shock of clearly nervous origin was so rare in the World War that almost no reference has been made to its treatment. It should be dealt with symptomatically—by rest and quiet, and, if the blood pressure remains below the critical level, by measures to increase the blood volume.

Primary shock due to mortal wounds or to excessive and sudden hemorrhage usually offers so little chance for treatment that nothing further need be said concerning it than that the principles developed in the foregoing pages should be applied when there is any hope of their being serviceable.

AFTER-CARE

It should be remembered always that the patient who has been in shock and resuscitated, and then operated upon, is in a precarious state. His nervous system has been disturbed not only by the original trauma, but also by the low nutrient flow of blood and by the surgical procedures incidental to operation. Rest is therefore essential, and should be secured, if possible, in sleep. Warmth should likewise be provided, but not to a degree which will induce sweating. It should be remembered that the blood volume has probably been reduced much more than the amount represented by the usual intravenous injection, and that the blood flow will not be normal until the volume is restored to the normal

level. Fluids should be continued, therefore, by mouth or rectum until the urine output equals the water intake. Furthermore, the patient should be attentively watched for unfavorable developments, and if they arise should be promptly treated.

SHOCK TEAMS, THEIR TRAINING AND DUTIES

A contribution to military organization made during the World War by the American Army was that of giving special training to medical officers who were assigned to the care of serious cases of shock and hemorrhage.[28] During the months from May to November, 1918, medical officers were sent to Dijon weekly and there received instruction regarding the nature of shock, the theories of its onset, its clinical manifestations, the conditions favorable to its development, and the principles of treating it, as outlined in the foregoing pages. Also they were disciplined in methods of matching blood and in the procedure of blood transfusion. The methods of instruction consisted of demonstrations of blood pressure measurements, the development of shock in a lower animal, and lectures and practical exercises in which the men determined their own blood pressures and their own blood groupings, and practiced transfusions on anesthetized animals. From these classes medical officers were selected who went to hospitals in battle areas and took charge of the shock wards. Their service to the surgeons has been highly commended.

A number of valuable pertinent points resulting from this experience may be summarized as follows:

(1) So far as possible, medical officers of field and evacuation hospitals should receive such instruction as is mentioned above and be detailed to take charge of shock wards in times of activity. At Dijon men from base hospitals, A. E. F., were given instruction, because it was believed that they could be called forward into battle areas in time of need. This proved, however, to be almost impossible, because base hospitals were quite as busy as forward hospitals during military engagements. (2) For each shock ward there should be at least two resuscitation teams, each consisting of a medical officer, a nurse, and an orderly. (3) Hopeless, moribund cases should not be sent to the shock ward; provision should be made for a separate place for such cases. The presence of a number of dying men in a crowded shock ward takes the time of the teams and interferes with efficiency and morale. (4) In the transfer of the wounded away from the front line, provision should be made, in wards close to the shock cases, for caring for at least some of the minor cases, and for men who have been gassed. Withdrawing 500 to 750 c. c. of blood from a man who has been only slightly wounded does him no harm, and that amount taken from a man who has been gassed may be serviceable to him; the blood thus obtained may save the life of a comrade who is suffering from shock or severe hemorrhage. (5) Officers in charge of hospitals should understand that men badly wounded require special care and that medical officers who have been particularly trained to give that care should have, so far as possible, free rein in making proper arrangements.

The duties of resuscitation officers are as follows: (1) To provide heating arrangements in anticipation of shock cases. These arrangements should

consist of hot-water bottles or canteens, means of getting hot water, and for applying hot air under fracture frames as described above. (2) To assure an adequate supply of transfusion equipment from the medical stores. (3) To arrange continually for an adequate number of donors, whose blood grouping must be determined. (4) To determine the blood grouping of all donors and recipients. (5) To be available for consultation with any of the hospital staff concerning transfusion. (6) To perform or direct personally all transfusions. (7) When possible, to obtain records of the clinical condition of the shocked men, in order to add information regarding the onset and the course of events in wound shock. (8) To perform such clinical work as the surgeon in charge may direct (this duty is mentioned with the proviso that no assignment will be made that removes the resuscitation officer from his important service in the shock ward).

Obviously, the shock team should cooperate closely with the surgical service. Resuscitation officers who have followed the progress of shock cases from the time of admission and who best know the limits of improvement in each case should give the surgeon their judgment of the optimum time for surgical intervention. Even apparently hopeless cases should be given the chance which surgery offers, though the percentage of recovery of such cases may be small.

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CHAPTER VIII

LOCALIZATION AND EXTRACTION OF FOREIGN BODIES UNDER X-RAY CONTROL

LOCALIZATION

EARLY HISTORY AND LITERATURE

In reviewing the methods of localizing foreign bodies, one is immediately impressed with the fact that the publications of the year 1896 set forth the principles at the foundation of most of the localizing methods of to-day. This year saw the publication of Buguet and Gascar,[1] setting forth the classical formula: Depth equals $\frac{b \times h}{a+b}$ when a represents the distance the tube is shifted; b the distance of shift of the shadow of the projectile; and h the height of the screen or plate from the focus of the tube. Early in this same year Thompson,[2] in America, and Imbert and Bertin,[3] in France, proposed stereoscopy in connection with X-ray localization. The method of making two exposures at right angles, the so-called method of right-angled planes, was proposed by White, Goodspeed, and Leonard.[4]

The following year marked the publication of Mackenzie Davidson and Hedley,[5] on the triangulation method, visualizing in space the position of the foreign body by means of crossed threads,and the method of Gerard [6] and Levy-Dorn [7] which utilized the same principle of triangulation, but without the cross-thread visualization. Stechow wrote further on the method of making two exposures at right angles.[8] Exner described a method combining a ring localizer with the triangulation principle, and later used the parallax principle.[9] The parallax principle was also used by Levy-Dorn.[7] Rémy and Contremoulins [10] described an elaborate apparatus which was apparently the forerunner of the Hirtz compass as used to-day.

In 1898, in addition to other methods, Morize used four small adhesive disks of lead; [11] two he placed at the points on the skin where the vertical ray passing through the foreign body entered and left the part; the other two were placed in a similar manner at right angles (or nearly so) to the plane of the first two. The intersection of the two diameters joining these four points gives the location of the foreign body.

Galeazzi [12] was apparently the first to publish description of the "pierced screen" the ordinary fluoroscopic screen with a small hole drilled through it and the lead glass cover, sufficiently large for the insertion of a small rod for estimating the depth from the screen surface to the skin in those locations where it was not possible to bring the screen in actual contact with the part under study. He also employed the triangulation method with single tube shift, and added a direct-reading scale, obviating the necessity of calculations.

Sechehaye,[13] in January of this year, published a review of the literature on the subject and was able to summarize 32 methods and authors.

The writer, in 1918, published a brief history of the development of foreign body localization by means of the X rays, with a bibliography containing more than 200 references.[14]

The more than 200 methods referred to in this review were really susceptible of classification under a few of the methods described in the first two years of the roentgen era. Few of the methods later published were anything more than rediscoveries or minor modifications of essential principles already discussed and used.

The Hirtz compass, though first used in 1907, was not referred to in literature until 1914.[15] Telephone probes and other localizers working on the magnet principle were innovations appearing shortly before the opening of hostilities in 1914.[16] The most complete work on the subject of foreign body localization was written by Ombredanne and Ledoux-Lebard.[17] Delherm and Rousset,[18] and Nogier [19] also wrote booklets on the subject.

The United States Army X-ray Manual was finally adopted as the working manual of the United States Army Medical Department, and in it a large section was given over to localizations.[20] An effort was made to select the more valuable methods and to standardize the necessary instruments and the technique for their operation under the methods selected. It was exceedingly difficult for those who had not actually participated in forward area surgery under battle conditions to realize how simple, direct, and quick the localizing methods had to be. It was soon recognized that any method involving the use of plate or film records was unsuitable because of the time and labor necessary to make the localization, and it soon transpired that the medical officers actually doing localization work in forward hospitals exhibited a marked tendency to employ very simple methods capable of being used without accessory instruments other than the fluoroscopic apparatus itself.

METHODS

Though civil surgery affords relatively infrequent opportunity for the surgeon or the radiologist to put to actual test the methods of localization which are to be found in every textbook on radiology, the World War afforded an extraordinary multiplicity of occasions for studying foreigh body cases, and enforced a careful analysis and modification of the more than 200 procedures which were described in the medical press early in the war.

Some of the procedures described are complex, some are simple; some require complicated apparatus or special instruments, while others may be carried out with any of the ordinary types of X-ray equipment; some required the aid of radiographic plates, while others are screen methods quickly performed and affording an instant answer to the surgeon's query as to the presence or situation of the offending foreign substance. Out of the war have arisen systematized localizing procedures, with standardized apparatus especially adapted to the expeditious handling of large numbers of wounded men. Some of the standardized types of apparatus developed for military work are already being used in our civil hospitals, and the general trend of manufacture

of X-ray equipment is toward the simpler instruments developed during the war.

It is the purpose to set forth briefly herein only those methods most readily learned and carried out with a minimum of accessory instruments. Explanations of geometrical propositions, for lack of space, are reduced to a minimum. Any reader interested in the details of such mathematical propositions will find discussions in the various excellent treatises on localization which have been prepared by the medical departments of the various allied armies, already referred to.

Magnets, vibrators, and telephone probes have been variously recommended by military surgeons but they are limited in their usefulness. Magnets, for instance, are applicable only to the localization and extraction of such metallic foreign bodies as are responsive to magnetic attraction, whereas the radiologic method should discover all metallic foreign bodies (with the possible exception of aluminum), besides many nonmetallic substances. The radiologic method as a part of the surgical procedure lends itself admirably to helping the surgeon during the extraction of any foreign body, whereas the magnet and vibrator methods above referred to have the same limitations in respect to nonmagnetizable substances.

The person undertaking a localization should not confine himself to an estimation of the depth of the foreign body, but should acquire all possible information afforded by an X-ray study of the case. For the best results it is essential that the radiologic work be done by a physician, or, better still, the surgeon should be familiar with the radiologic procedures involved in foreign body localization; indeed, there is such temptation for the surgeon himself to go ahead with the radiologic part of the extraction procedures that unless he has a thorough technical knowledge of the subject he is likely to harm himself through inadvertent overexposure to the rays. These dangers will not be discussed here as they are fully described in numerous textbooks.

Localizations are usually accomplished by fluoroscopic methods, although there is no objection to radiographic methods other than that they involve more time and expense and are not so informing as the screen methods. Stereoscopic radiograms are more valuable than single plates.

A localization should afford the following information: (1) Anatomical data, showing the relation of the foreign body to neighboring structures, such as a trochanter, a condyle, or some other well-known bony point, to a muscle; or to an artificial opaque marker affixed to the skin. The condition of any injured bones should be carefully recorded. (2) Mathematical data as to the depth of the foreign body in relation to marks or markers on the skin. (3) Directions which will guide the surgeon to the foreign body. This guidance is frequently afforded by the fluoroscope through observations made during the removal of the foreign body.

The following localizing methods are considered herein: (1) Rotation of the part; study of the movements of the shadows of the projectile or other foreign body in relation to neighboring opaque structures or skin markers. (2) The "nearest point" method. (3) The parallax method, which is often combined with the nearest point method. (4) The orthodiagraphic method, which is

also often combined with the nearest point method. (5) The method of right-angled planes (four-point survey). (6) The multiple diameters method. (7) The single-shift triangulation method, with which may be included the stereoscopic method. (8) The double-shift fixed-angle methods. (9) Harpooning methods, combined with reconstruction of the part by the aid of a cross-section anatomical atlas.

There are numerous other methods which might be described, but these mentioned above are all very simple, easily learned, quickly performed, and accurate to within a half centimeter, without the aid of plates. There is no reason why one or more radiograms of the part should not be made if the surgeon so desires, especially if he has not been present at the X-ray localization. If such plates are made, they should be stereoscopic plates.

Apparatus Required

In addition to the usual current-generating apparatus of any type supplying a milliampere or more, a tube of sufficient hardness and a horizontal [a] or vertical fluoroscope installed in a room capable of being completely darkened, the following items of equipment are necessary: A ruler; a localizing rod or wooden stick the size and length of an ordinary lead pencil, with a metal ring, approximately 2 cm. in diameter, screwed into one end, and an ordinary screw with a

Fig. 109.—Palpator made from a small wooden rod, with a screw and a screw eye

well-rounded head in the other; grease pencils, such as are used for marking on glass or chinaware; suitable skin-marking ink; an aniline dye may be used, or the Finzi ink;[b] a cross-section anatomy, that published for Professor Symington, being highly satisfactory.[21]

The foregoing accessory articles permit the performance of most of the localizing procedures listed and described in this article, but the following inexpensive and simple accessories are often very useful: Large calipers, such as obstetrical calipers; a foot-switch for controlling the current through the X-ray tube; better still, a combination switch, controlling both the overhead light and the tube current; strips of flexible metal, such as composition tin, 1.5

[a] It is assumed that the majority of the work will be done with the standard X-ray table by fluoroscopic methods and with the tube below the table. The tube box is movable in two directions, as in the usual trochoscope, and is provided with a double shutter giving a diamond-shaped opening with the diagonals parallel and perpendicular to the length of the table and also with an adjustable slit, under separate control, parallel to the length of the table. The tube box runs freely and may be locked in any position against both lateral and longitudinal movement, and is also provided with a simple means for fixing the amount of tube shift for a particular purpose or for measuring any shift from a fixed position.

The fluoroscopic screen is carried by a ball-bearing carriage mounted on the table rails, and provision is made for a movement parallel to the table, for rotation about a vertical axis and also for a vertical shift. Each of these movements may be prevented by a suitable, convenient lock. The fluoroscopic screens are perforated with a small hole through which a marking device may be inserted to mark the skin in the vertical ray. When this ray is spoken of it is assumed that the table will be substantially in a horizontal position and that a line joining the target with the center of the diaphragm will be perpendicular to the plane in which the tube may move. The opening in the screen also serves a very convenient purpose in temporarily fixing in position the scales and other pieces of apparatus which it is desired to use on the fluoroscopic screen.

[b] The writer prefers an ordinary indelible pencil which makes a semipermanent mark on the moistened skin. For war surgery the indelible pencil would hardly satisfy the need, but in civil practice it will usually do very well.

or 2 cm. in width, and of appropriate lengths for surrounding an arm, a leg, or the torso, and hinged together in pairs; a cannula and trocar, and a supply of fine piano wire cut into lengths somewhat longer than the trocar.

Centering the Tube

Accuracy in localization work requires an exactly centered X-ray tube. Some of the French manufacturers supply a special device for centering the tube. Among the numerous groups of rays given off in the active hemisphere of an X-ray tube is one to which the term "normal ray" has been applied. It will be recalled that in geometry a line normal to a second line is one perpendicular to it, making with it two right angles. In radiology, therefore, the term

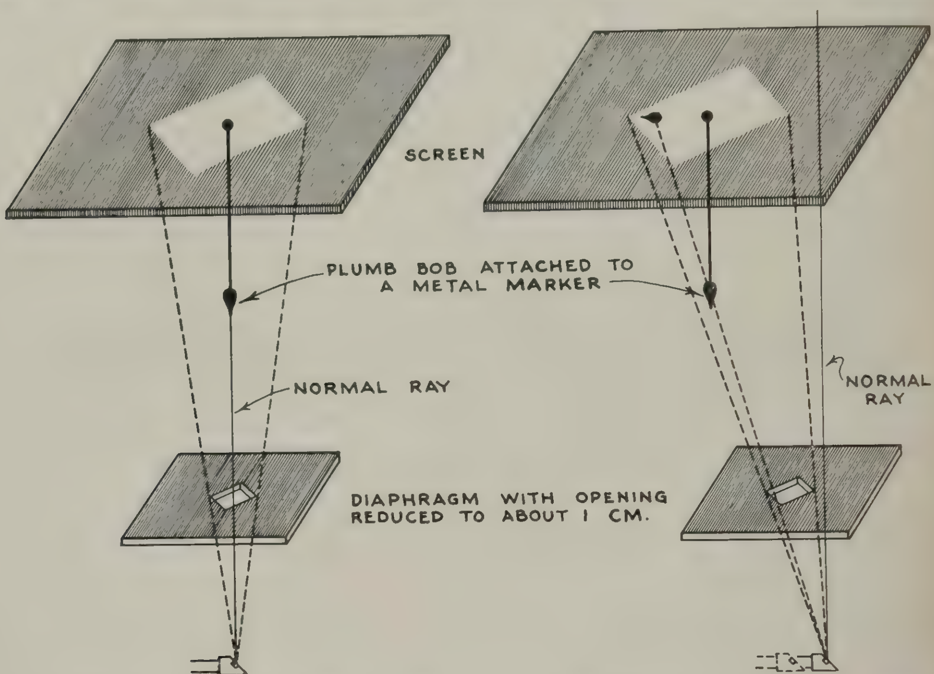

Fig. 110.—Showing the positions of shadow of plumb bob on fluorescent screen when X-ray tube is properly centered, and when off center

normal ray is applied to that group of rays perpendicular to the long axis of the tube. Unless the tube is carefully centered beneath the diaphragm in such a way that when the diaphragm is closed down to a small opening the normal ray will pass through it, there will be a resulting error in the localization calculations.

One may determine when the tube is centered by the following means: When the military type of table is not available, the screen is locked in position above the tube box and a plumb bob attached to a metal marker, such as a lead ball, is affixed by adhesive plaster to the underside of the screen somewhere near its center (fig. 110). The opening in the diaphragm is reduced to about 1 cm. and the tube box moved until the pencil of rays emitted through the small opening casts the shadow of the plumb bob and the metal marker on

the screen. If the two shadows do not coincide, the tube is not correctly centered, and alterations in its position should be made and compared until the two shadows coincide.

An ordinary tin cup or a glass tumbler may be placed accurately over the small opening in the diaphragm, care being taken to see that the cup or tumbler is on a level support, and that the opening in the diaphragm comes as near as possible to the center of the cup. Then the diaphragm is opened so that the shadow of the whole cup shows. One may judge by the symmetry of this shadow whether or not the tube is properly centered (fig. 111).

With the table supplied by the United States Government during the war, the diamond-shaped opening of the shutter is reduced to about 1 cm. The tube box is locked in position and the screen moved so that the perforation in its center will coincide with the center of the projection of the small

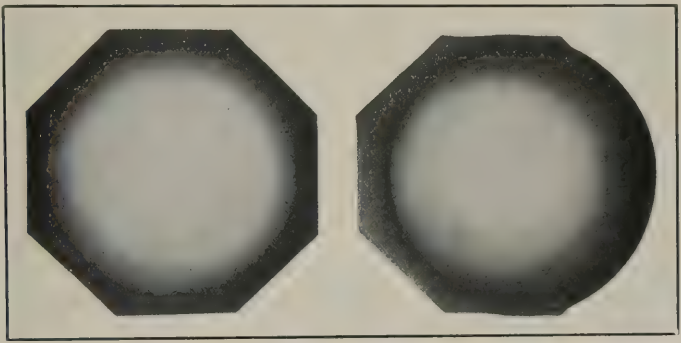

FIG. 111.—Screen appearance of a tumbler with the tube properly centered and not properly centered

diagonal opening of the shutter. The carrier is locked against longitudinal motion and against rotation, and the screen raised by the vertical movement of the carrier. If the perforation does not retain its symmetrical position the tube needs shifting until this condition obtains.

It is important that this process of centering the tube be carried out each time a localization is attempted, unless a number of localizations are planned for the same day.

Marking the Skin

For marking the skin in relation to foreign bodies, especially where there is only occasional need for localization work, the ordinary indelible pencil, dipped in water or used on the moistened skin, is quite satisfactory. This mark is not obliterated by painting the skin with tincture of iodine. If a black mark is desired, which dries quickly and which will withstand scrubbing, the Finzi formula is useful: Pyrogallic acid, 1 gm.; acetone, 10 c. c.; liquid chloride of iron, 4 c. c.; wood alcohol q. s. ad., 20 c. c.

This ink, when made up fresh about once in 10 days, makes a black mark and dries quickly. It is best applied with a sharp stick or a fine brush. If allowed to dry thoroughly the mark will resist alcohol, show through an iodine stain, and persist from two to seven days.

In emergency cases a persisting mark can be made with a stick of silver nitrate on the skin moistened with a few drops of photographic developer. A match or toothpick dipped in a 10 or 20 per cent solution of silver nitrate will serve the same purpose without the irritation of the skin which sometimes results from the use of the silver nitrate stick. An aqueous solution of brilliant green has also been suggested for marking the skin.

The method of marking will vary with the case. If multiple foreign bodies are present, it is sufficient to mark such of them as can be located by the "nearest point" method with a dot surrounded by a circle, the dot indicating the nearest point. In cases of a single foreign body it is well to make as many marks as may be helpful to the surgeon; for instance, one mark perpendicularly over the foreign body recording its depth, with two horizontal marks on either side of the part in the plane in which the foreign body lies.

It is also highly important that the localization be carried out and the marks placed upon the skin in the position which the patient is likely to occupy while undergoing operation. Hence, when it is feasible, the surgeon or his assistant should be consulted as to the probable method and site of surgical approach. It should be stated as an axiom that in all localization work the patient should be carefully placed in the operative position before one begins to make the localizing marks.

TECHNIQUE

One of the first steps in the localization of a foreign body, after determining its presence, is an estimation of its approximate position—whether it lies in front of or behind a certain bone or other anatomical landmark, whether it lies within the substances of a great muscle, etc. This is termed the anatomical localization, and it often suffices to enable the surgeon to perform the extraction.

Extraction of the foreign body is often one of the lesser considerations in dealing with a gunshot or other emergency case. The proper toilet of the wound, the removal of clothing and other foreign materials which may be carried into the part by the projectile or foreign body, as well as attention to damaged bone, nerve, or other tissue, are of paramount importance, and in many instances the extraction of the offending foreign body comes in for secondary consideration. Along with the data for localization the radiologist should supply all information possible regarding injury to bone, dislocations, blood or pus accumulations, gas infections, and other conditions relating to the wound.

Anatomical Localization

From the surgical standpoint, it may be stated that it is more important for the surgeon to be informed of the anatomical situation of a foreign body than of the mathematical distance it lies perpendicularly below a given point on the skin. For example, the surgeon is more interested in knowing that a foreign body has penetrated the pleura than that it lies 4.5 cm. below a certain point on the back when the patient is lying prone; and whether a projectile recorded as being 7 cm. beneath a point just below the vertebra prominens is intrapleural or lies within the substance of the body of the last cervical or the first dorsal vertebra. In order to give this information it is essential that the

radiologist should possess an accurate knowledge of anatomy. It is here that the cross-section anatomies may lend considerable aid, though sometimes anatomical conditions vary in individual cases on account of unusual accumulations of fat and because of varying build in different individuals.

The anatomical location can often be determined by requiring the patient to carry out some active movements, or the radiologist can himself move the part and observe the changing relations of the foreign body during these maneuvers. The movements of the shadow during the contraction of muscular masses are significant. For instance, a foreign body in the forearm which exhibits considerable displacement when the patient closes his fist manifestly lies in one of the flexor muscles; if it ascends on flexion of the thumb and remains stationary during movements of the other fingers, it obviously lies in the flexor muscle of the thumb.

Foreign bodies in the region of the eye may be more exactly localized by causing the patient to open and close the eyes, to rotate the eyeball, and to carry out other movements which bring into play the individual eye muscles. A method of localization of foreign bodies in the eye will be considered later in this discussion. By having the patient protrude the tongue, open and shut the mouth, perform movements of deglutition, swallow a capsule containing bismuth, etc., one is able to determine the relative anatomical position of a foreign body in the face or neck.

For differentiation between intra- and extra-thoracic foreign bodies, it is usually sufficient to cause the patient to practice several deep inhalations and exhalations. During inspiration the lung is displaced from above downward, while the thoracic cage is displaced in a contrary sense. Lateral or oblique fluoroscopy of the chest is very important, especially when the patient's diaphragm is immovable. Unless rather definite and extensive movement of a foreign body in the lower half of the chest can be determined during respiratory movements (save when the diaphragm is motionless), it should not be considered to be intrapulmonary: in the upper part of the thorax intrapulmonary foreign bodies may exhibit very little respiratory movement, and in the middle of the lung on either side they may be quite stationary. As intrapulmonary and hilus calcifications have caused many errors in the study of intrathoracic foreign bodies, it is well to have stereoscopic plates made in all doubtful cases. The pulsation imparted to intrathoracic foreign bodies by the heart or great vessels, especially to those lying near the midline, may occasionally cause great difficulty in exact localization.

Foreign bodies lying within the pericardium are usually movable and gravitate to the most dependent point possible when the patient changes his position; in old cases, intrapericardial foreign bodies may be attached to the wall of the pericardium and render the diagnosis more difficult.

Projectiles lying near the diaphragm, but just above it, should be easily localized, provided one views the patient from a sufficient number of angles. Intraabdominal, subdiaphragmatic foreign bodies are not so easily localized. Stein and Stewart [22] have recommended the introduction of oxygen or some other gas into the peritoneal cavity, so that by changing the posture of the patient it is possible to separate the subdiaphragmatic structures from the

diaphragm itself. Many cases of wounds with intraabdominal projectiles will have developed sufficient gas in the peritoneal cavity to make the introduction of oxygen unnecessary. Careful palpation of the abdomen, inflation of the colon or stomach in selected cases, the use of the Trendelenburg position, etc., will usually be sufficient without an induced pneumoperitoneum. Viallet and Tanton[23] have called attention to the possibility in certain cases, especially in wounds of the urinary bladder, of localizing a foreign body inside a hollow organ if, by localizing alternately from the anterior and the posterior aspect of the torso, results are obtained which disagree as regards the total thickness of the subject and are notably less. This is due to the displacement of the projectile from one position to the other.

In considering foreign bodies in relation to the vertebral column, attention should be drawn to the great value of stereoscopic plates and to lateral radios-

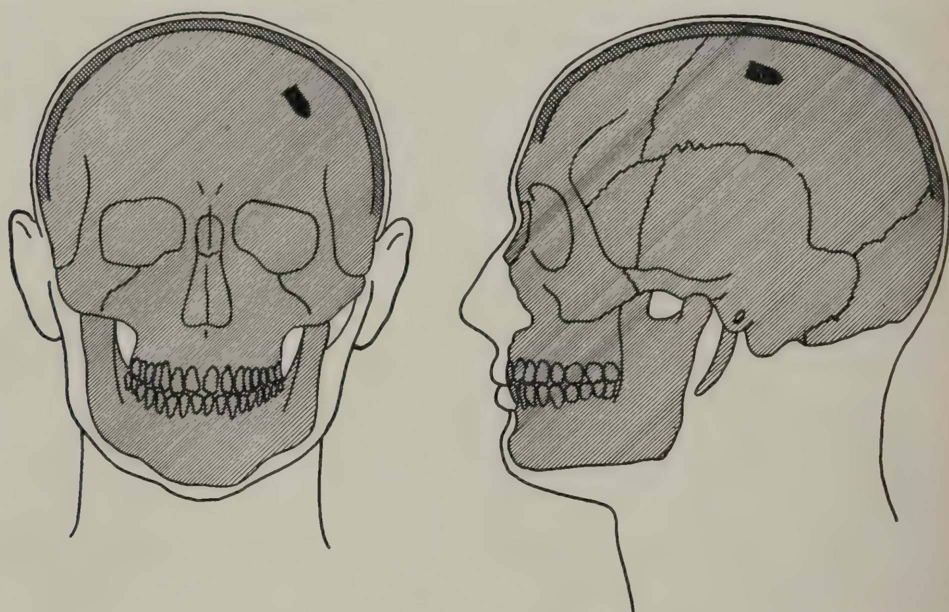

FIG. 112.—Screen appearance of an intracranial foreign body

copy and radiography of the spine, too little practiced by the average radiologist. Lateral radiography of the spine is generally considered impossible without extraordinary apparatus; on the contrary, the average type of portable apparatus will suffice to make excellent radiograms if intensifying screens are used. Even the sacrum can be radiographed laterally in this manner.

Foreign bodies in the pelvis should be localized with ease provided one makes stereoscopic radiograms. In occasional cases it may be possible to gain more information concerning a foreign body located in or near the rectum if an assistant makes intrarectal manipulations at the moment of the X-ray examination.

In wounds of the head it is sometimes possible for the casual X-ray observation to be very misleading. This is demonstrated in Figures 112 and 113. In Figure 112 a typical intracranial projectile is shown in the frontal and lateral

projection. Figure 113 represents the actual position of a projectile which is extracranial and lies within the soft tissues of the temporal region, but which with the usual frontal and lateral X-ray projection appears to be intracranial. This error would hardly occur during a fluoroscopic localization, but it would be entirely possible with a radiographic procedure, and the possibility should be duly noted.

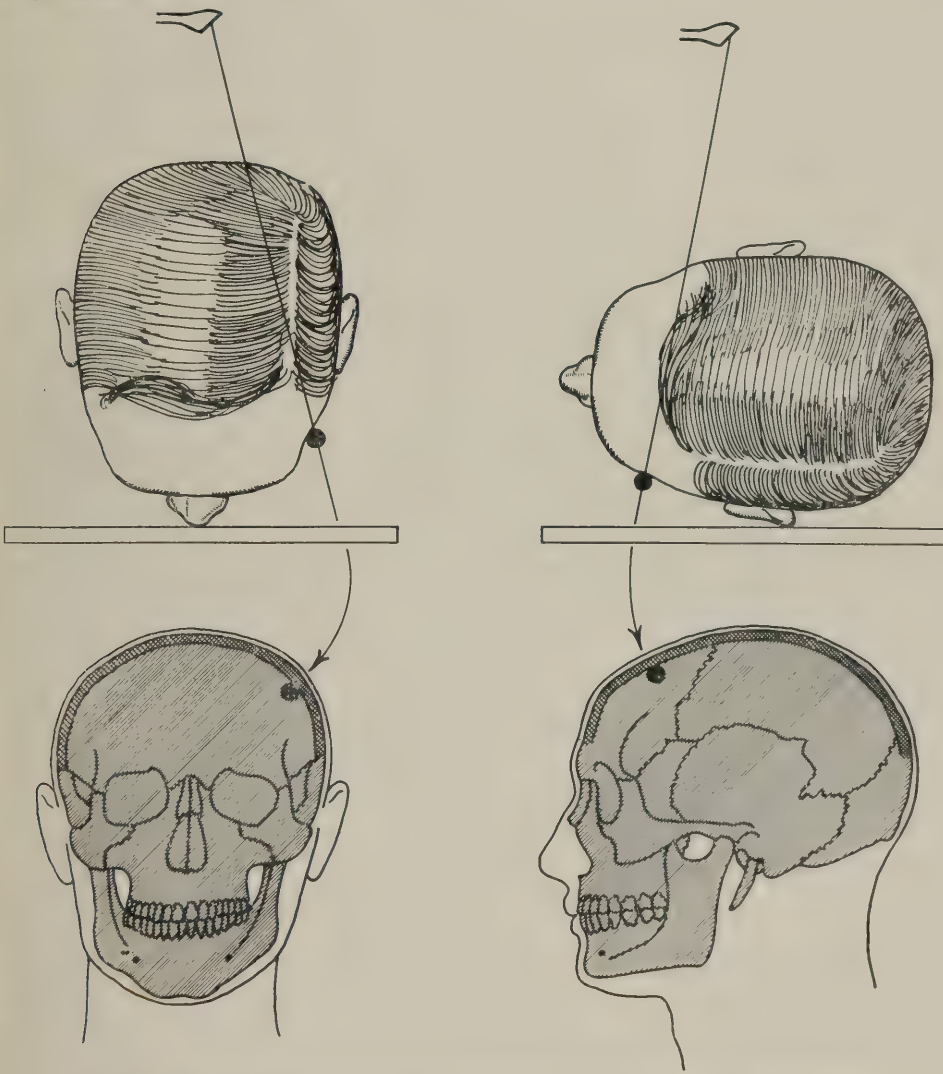

FIG. 113.—Screen appearance which might lead to an erroneous diagnosis of intracranial foreign body

In a routine examination the patient is first placed on the horizontal fluoroscope and a brief fluoroscopic survey made to determine the presence of a foreign body. Of course, one may deal with foreign particles too small to be seen with the fluoroscopic screen, but except in the eye and a few other similar critical locations, a metallic foreign body too small to be seen with the fluoro-

scope usually does not require extraction. When the eyes are properly prepared by a preliminary stay in a darkened room one may see on the screen the shadow of such small substances as a common pin or a bird shot in the cecum or a fairly small foreign body in the eye. In civil practice one or more radiograms will be made in nearly every foreign body case. In France more than 5,000 wounded men passed through the X-ray department of a certain unit without a single plate being made, all the localizations being done by the screen method.

Rotation of the Part

The presence and general locality of the foreign body having been determined, it is easy by rotation of the member or part to determine the relative depth of the foreign body in relation to bony landmarks or other opaque structures or markers. The shadows which move in the direction in which the part is rotated (figs. 114 and 115) will be found to lie between the axis of rotation of the part and the fluorescent screen; in other words, nearest the screen or nearest the upper surface of the part. On the other hand, if the shadow of the foreign body is displaced in the opposite direction to that in which the part is rotated, the foreign body will be found to lie between the axis of rotation of the part and the tube; in other words, nearest the inferior surface of the part or member. This is illustrated in Figure 114 (after Nogier) where projectile P^1 is located near the upper surface, and P^2 near the lower surface of the limb. When the part is rotated to the right, in the direction of the arrow *a*, naturally the shadow of projectile P^1 travels toward the right and the shadow of projectile P^2 toward the left. P^1 therefore lies above the axis of rotation of the part and P^2 between the axis of rotation of the part and the tube.

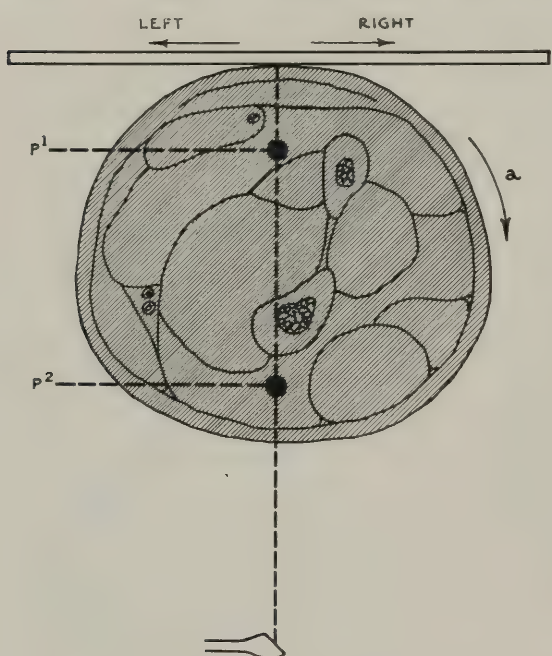

Fig. 114.—Method of rotation of the part. (Nogier)

Nearest-Point Method

After the above-described method of rotation has enabled one to form an opinion as to the general situation of the projectile, the next step is to palpate the part containing the projectile and at the same time to observe on the screen the results of the palpation. One will not employ the unprotected fingers for the purpose, but rather the localizing rod (fig. 109) or any suitable pointer. By the movements of the foreign body under pressure upon the soft tissues sur-

rounding it and by the amount of pressure required, one may estimate very accurately the point upon the skin which is nearest to the foreign body, and by simultaneous rotation of the part the depth at which the foreign body lies. In utilizing the palpating rod, one should turn the part until the position is found in which the shadow of the projectile or foreign body will be as near as possible to the surface. This done, the part is explored by touching it with the extremity of the palpating rod while making light vibrating movements. The nearer the end of the palpator to the "nearest point" the more will the foreign body move with these slow vibrating movements. When the movements transmitted by the palpator show the maximum mobility of the foreign body, this point on the skin should be marked as indicating the shortest possible distance from the foreign body to the skin.

This method is, of course, best adapted to the foreign bodies which are relatively superficial, as in the soft tissues of the arms, legs, neck, axilla, and buttocks; but it is a fact that fully one-half the foreign bodies may be included

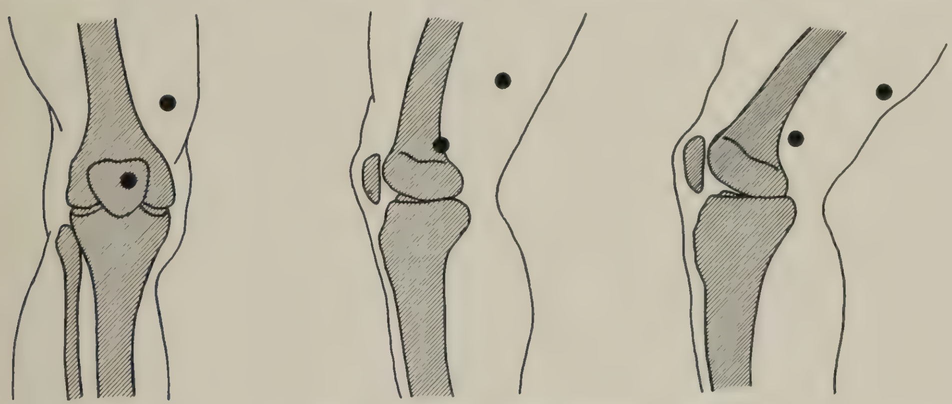

FIG. 115.—Method of rotation of the part

in this class. It is also frequently of value in demonstrating that a foreign body is within a joint, or that a foreign body can not be displaced by pressure, suggesting that it may be embedded in very firm deep tissue or in bones.

The nearest point having been marked, the depth of the foreign body is next determined by one of the following methods.

PARALLAX METHOD

This method is based upon the experimental fact that two opaque markers placed at an equal distance from the screen will, when the tube is moved, cast upon the screen two shadows whose range of movement is equal; that is, whatever may be the displacement of the tube, objects lying in a plane parallel to the screen will project their shadow upon the screen in parallel lines. In Figure 116, for instance, T^1 and T^2 represent two positions of the tube; P, the projectile; L, the palpating rod held against the part at the same level as the projectile; P^1 and P^2, the shadows of the projectile with the tube at T^1 and T^2, respectively; and L^1 and L^2, the shadows on the screen of the end of the palpating rod under the same circumstances. The line L^1 and L^2 represents the excursion of the

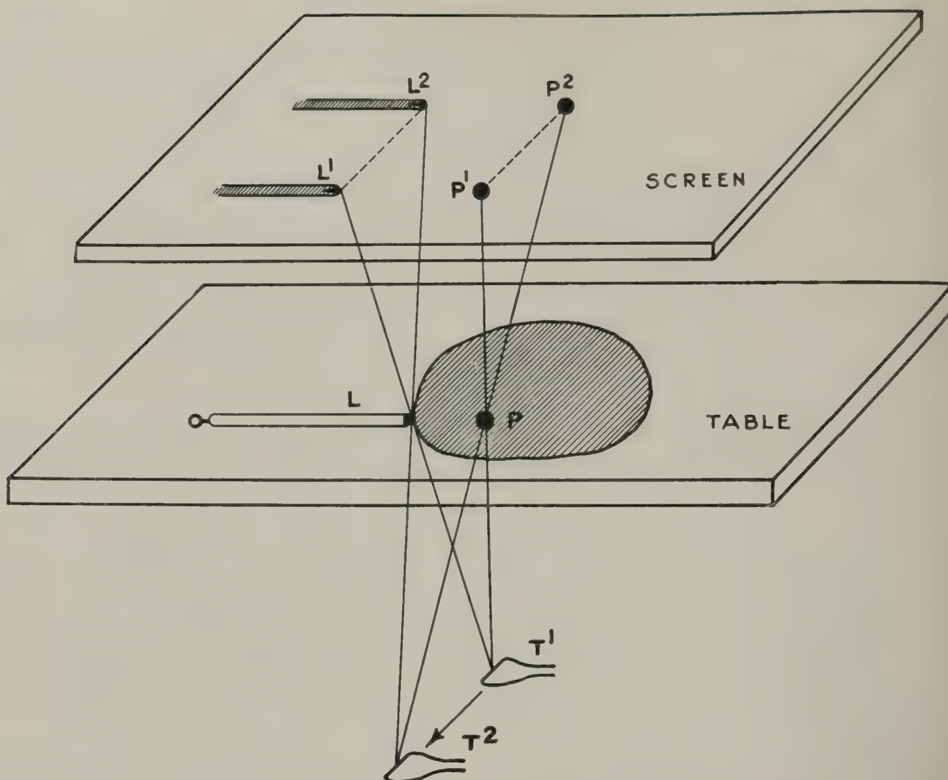

FIG. 116—Diagrammatic representation of the parallax method

shadow of the palpator as the tube is moved back and forth from T¹ to T²; and the line P¹ P², the excursion of the shadow of the projectile P. It is obvious that when the foreign body P and the end of the palpating rod L are at an equal distance from the tube, the excursion of their respective shadows will be equal and the lines L¹ L² and P¹ P² will be equal. When the foreign body is nearer the tube than the palpating rod, the excursion of the shadow of the foreign body will be greater than that of the shadow of the palpator; on the contrary, when the palpator is in a plane nearer the tube, the excursion of its shadow will be greater than the excursion of the shadow of the foreign body.

This maneuver is carried out as follows: The end of the palpating rod is placed against the part as near as possible to the foreign body and in what

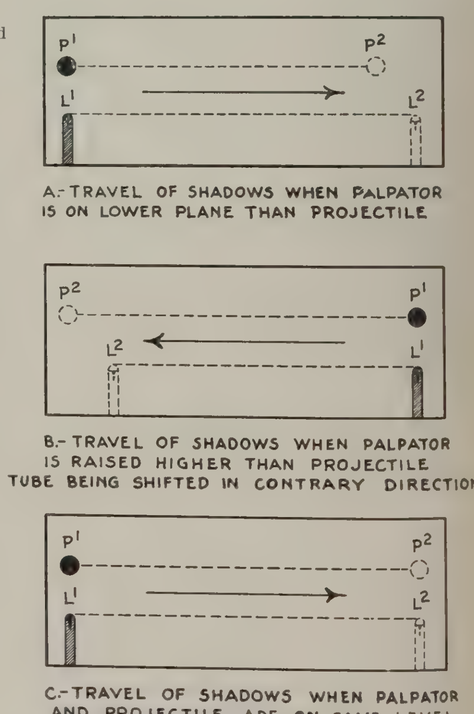

FIG. 117.—Screen appearance during different steps of the parallax method

seems to be the plane of the foreign body, and both shadows are brought to the edge of the shadow of the opened diaphragm. The tube is then deliberately moved in such a way as to cause the shadows to travel to the other edge of the open diaphragm. In Figure 117, *a*, the foreign body shadow lags behind the shadow of the palpator in reaching the mark, therefore the palpator is in a plane deeper than that of the projectile. If one raises the palpator slightly in order to correct the error (fig. 117, *b*) and moves the tube just enough to bring both shadows again to the edge of the diaphragm, the tube is shifted in the contrary direction, causing the two shadows to return to the first position. This time the shadow of the projectile travels faster than the palpator, and it is evident that the position of the palpator was overcorrected and brought nearer the surface than the foreign body. Once more a correction is made, as shown in Figure 9, *c*, and now, when the tube is shifted, both shadows arrive at the other edge of the diaphragm simultaneously. The screen is then removed and a horizontal mark placed upon the skin at the level of the palpator point. From this it is easy to deduce the distance at which the foreign body lies from the surface of the part. The procedure may be repeated on the other side of the part if it be an arm, leg, head, or neck.

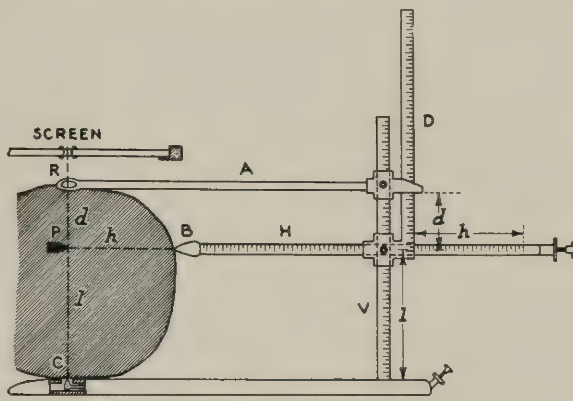

FIG. 118.—Schematic drawing of parallax localizer. V, Upright; R, ring; B, ball; P, foreign body; C, opening in base

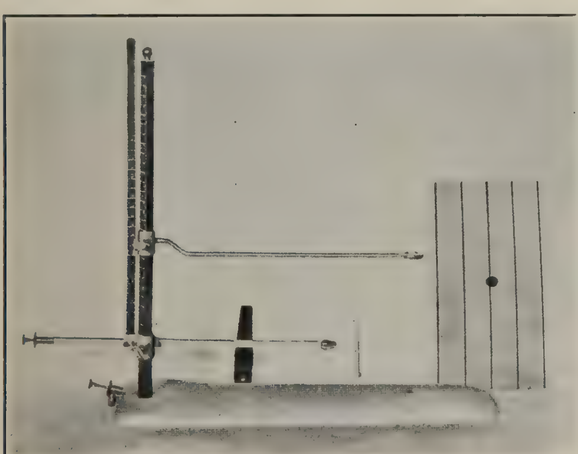
FIG. 119.—Apparatus shown in Figure 118

This method is also valuable in connection with fluoroscopic screen control of foreign body extractions carried out during operation, for it permits the radiologist to tell the surgeon whether the end of the seizing forceps lying in the wound is above or below the foreign body to be extracted.

Figure 118 is a schematic drawing showing the parallax localizer provided for the United States Army Medical Department. Figure 119 is a photograph of the apparatus itself.

ORTHODIAGRAPHIC METHOD

Another simple means of ascertaining the exact distance from the foreign body to the nearest point on the skin is the orthodiagraphic method (fig. 120). The part is rotated until the shadow of the foreign body P and the marker upon the nearest point P^1 lie in the same plane. With the part held in this position, the tube is shifted until the shadow of the foreign body lies in the middle of the illuminated field upon the screen. The diaphragm is then narrowed down to the smallest possible opening which will illuminate a field upon the screen larger than the foreign body, the screen being held in a horizontal position parallel to the table and perpendicular to the central ray. The shadow of the foreign body is then brought to the center of the small illuminated field upon the screen at *a* and a mark made upon the screen at this point with a grease pencil. The screen being held rigidly still, the tube is shifted until the small illuminated field shows as its center the marker upon the skin at a^1.

The distance aa^1 is equivalent to the distance PP^1, the depth of the foreign body from the nearest point upon the skin.

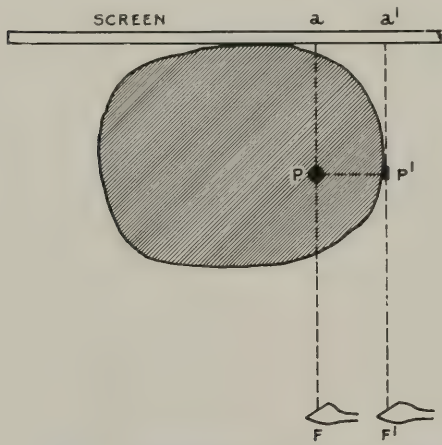

FIG. 120.—Orthodiagraphic method of localization

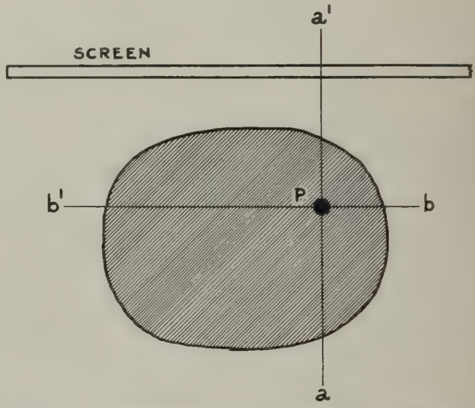

FIG. 121.—Measurement in two directions (right-angled planes)

METHOD OF RIGHT-ANGLED PLANES

Another simple method of localizing the foreign body is the four-point survey or the method of right-angled planes (fig. 121). This method is applicable only to those parts which can be rotated, unless a special instrument for fluoroscopy in both the vertical and lateral position is available. Special apparatus has been designed for simultaneous fluoroscopy of a part in two directions at right angles to each other.

We first pass the normal ray through the projectile P in the direction aa^1, and by means of the ring marker the point of exit and the point of entry of the vertical ray are marked on the skin (fig. 122). The part is then rotated through approximately 90°, when for a second time the normal ray is made to pass through the projectile, now in the direction bb^1, and these two points again ascertained by means of the ring marker and indicated upon the skin. The

localization of the foreign body is thus definitely determined at the crossing of the two axes, and with the aid of a cross-section anatomical atlas one may reconstruct the part and the position of the foreign body. One may rotate the tube instead of the part if the apparatus permits it. It is not essential that the two planes of observation be at right angles; the crossing of any two axes through the foreign body will indicate its position.

This method is slightly less accurate than the multiple diameters or six-point survey.

MULTIPLE DIAMETERS METHOD

The multiple diameters method consist simply in securing several lines of sight through the body, each of which is made to pass through the projectile. The point of entry and the point of exit of the normal rays used in establishing these lines are plainly marked upon the skin. It is, of course, essential that a small diaphgram opening be employed in these methods.

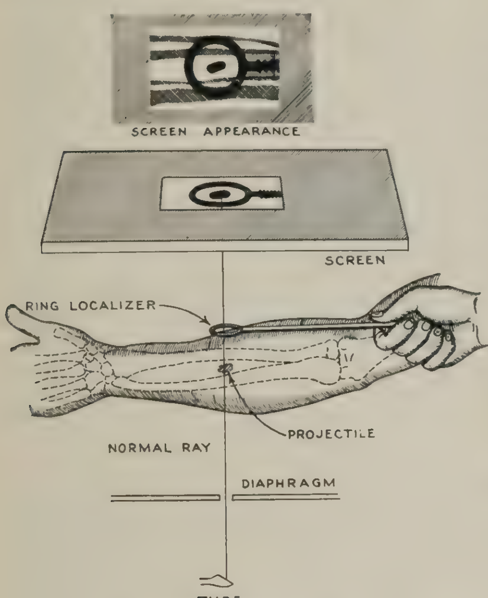

Fig. 122.—Screen appearance of, and method of using, the ring localizer

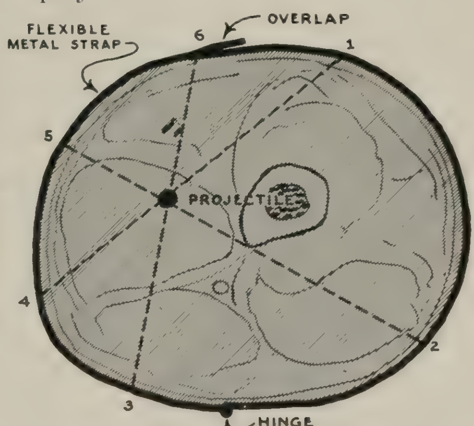

Fig. 123.—Malleable band, and the six-point survey methods

The method of multiple diameters combined with the use of the strips of malleable metal, as employed by several authors, was as follows: [20]

Two pieces of flexible metal, such as a composition of tin, are hinged together in the middle and placed around the body in the plane of the skin marks and made to conform to the shape of the body. Note is made of the distance that one unhinged end overlaps the other, and the skin marks are transferred to this metal band. After carefully removing the latter from the body, it may be laid down on a card or a sheet of paper, and by bringing the overlapping end to its original position a pencil tracing will show the outline of the body in the plane of examination. The skin mark positions are then transferred to the diagram so as to make an approximate duplicate of the shape of the body and the location of the external skin markings.

If, on this diagram (fig. 123), one numbers the skin marks in series, 1, 2, 3, 4, 5, and 6, and joins 1 and 4, 2 and 5, and 3 and 6, and if the work has been

strictly accurate—that is, if the sight lines were properly established—if the shape of the body did not alter by change of position when the band was put on, if the band was properly formed and not distorted afterwards these three lines will intersect at a point; as a rule they are likely to form a small triangle, but with an excellent chance of the projectile being located in this small area. If one now compares the diagram, so formed, with a cross section anatomy for the same region of the body, definite anatomical information as to the position of the projectile and the relative position of muscles or organs likely to be encountered in its removal is gained.

The value of this method will depend to a considerable extent upon the care exercised in forming and handling the strip and in properly adjusting it to the cross section anatomy. It is suggested that in many cases at least one of the skin marks might well have a definite relation to some anatomical landmark, so that there could be little opportunity for a rotation of the band with reference to the anatomical chart. This will be especially true of portions where the cross section is nearly a circle. It should also be observed that the accuracy of this method increases when the three sight lines are made to differ materially in direction. In some cases, this would be a difficult matter, as with a seriously wounded patient, or one for whom change of position on the X-ray table would be painful.

Lacking malleable metal strips one may make a cardboard cutout conforming to the contour of the part, and transfer to this cutout the skin marks indicating the points of entry and exit of the lines of sight above referred to. This cardboard is not, however, so easily sterilized and taken into the operating room as a guide for the surgeon.

SINGLE-SHIFT TRIANGULATION METHOD

One of the earliest procedures of foreign body localization, as noted above, was that set forth in 1896 by Buguet and Gascar[1] who applied to foreign body localization the classical formula, depth $= \frac{bh}{a+b}$, where a represents the distance the tube is shifted; b the distance of the shift of the foreign body shadow; and h the height of the screen or plate from the point of focus of the tube.

The patient is placed upon the couch in the position he will occupy during operation and the screen fixed horizontally above the part and resting on it. The tube is moved about until the foreign body shadow lies in the normal ray, and a mark is placed on the skin at the points of entry and exit of the normal ray. The position of the projectile is further marked upon the lead glass of the fixed screen. On opening the diaphragm the tube is shifted any distance, say 10 cm., without disturbing the position of the patient or screen, and the new position of the shadow of the foreign body is marked upon the screen. By measuring the height h from the screen to the point of focus of the tube, the distance a the tube is shifted, and the distance b the shadow of the foreign body was moved, we are able to work out the formula above stated and to arrive at the depth of the foreign body below the screen. In order to determine the exact depth below the skin, it remains only to subtract the distance from the screen to the skin, if the skin and the screen are not in contact. This method

may be worked out accurately without arithmetical computation by simply redrawing the procedure to scale.

In civil practice, where only the occasional localization case is encountered, there is no necessity for maintaining a fixed distance between the screen and the focus point, for all these distances and shifts can be easily measured. In war, it will be better to adopt a standard focus-screen distance h (55 or 60 cm.) and a standard tube shift a (10 cm.), and to construct tables by which the depth of the foreign body below the screen can be instantly read from the shadow shift. Many such tables and many graphic devices were published during the war. The device intended for use by medical officers of the United States Army during the late war is illustrated in Figures 125 and 126. For use of this apparatus it is

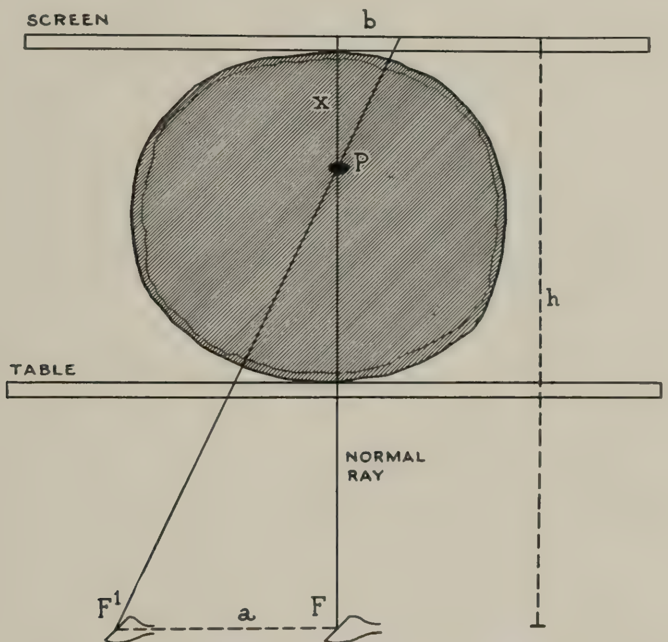

FIG. 124.—Classical single-shift triangulation method

better to employ: (1) A fixed tube shift of 10 or 15 cm. may be used or an image shift of an exact number of centimeters. (2) A fixed target-screen distance may be used. This is not, however, always convenient. (3) The exact setup of Figure 124 may be reproduced by use of a device shown in Figure 125, which may be supplied in case of a desire to use this method.

This device consists of two straight bars, A and B, at right angles to each other. B carries an adjustable slider, R. A carries two sliders, E and G. E is not moved after one adjustment unless a new table is used. The slider, G, has notches, 0, 1, 2, etc., 1 cm. apart, and a slider, P_1, with a latch engaging these notches. A scale, S, with its zero point at the upper end is carried by G. A lug at H is in line with the zero of G. If, now, DH-tube shift, GH-target-screen distance, P_1O-image shift, then a straight line, P_1D will cross the scale, S, at the depth of the foreign body below the screen. The instrument should

be fastened to the wall in a convenient place and the measurements needed should be made by a caliper, thus avoiding any reading of scales except the final depth.

If in the particular case illustrated, the image shift is 4 cm. and the zero point of scale, S, is set above H an amount equal to the target-screen distance, and DH is the tube shift for an image shift of 4 cm., a string drawn as indicated will cross the scale at a point P. The scale reading at this point is the depth sought.

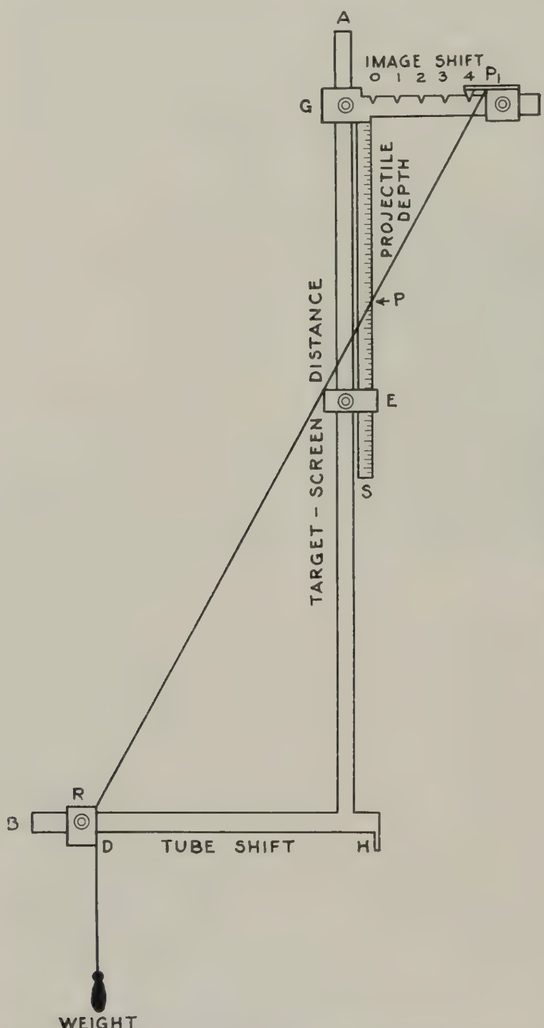

FIG. 125.—Wall meter, or indicator, for tube shift method, also showing method of using adjustable double-slider caliper

When using the standard table the slider, E, is adjusted so that a length measured on the screen-carrier support will show how much above E we must place G in order that GH may represent the target-screen distance.

It will be observed that this instrument serves to reproduce tube and image positions as actually observed by the roentgenologist; i. e., one vertical ray in which the skin is marked, and one oblique ray whose intersection with the former corresponds to the distance of the projectile from the screen.

An accessory device is also supplied, consisting of a strip of celluloid with a pin centering in the perforation of the screen, and having centimeter divisions clearly marked both ways from the center, making it quite easy to secure an exact number of centimeters displacement.

There is a considerable advantage in making the distance the image is shifted a definite number of centimeters, and measuring the tube shift, since the relative error in measuring the small length of image shift is greater than that in measuring the long tube shift.

When supplied with the accessories indicated above, this method becomes as expeditious as others, and is as accurate as any of the depth methods.

In the single-tube shift method there are various procedures which may be used. They all require essentially the same data, namely, (1) tube shift.

(2) image shift, (3) target-screen distance. If these distances are measured to scale in centimeters, it is possible to compute the end result.

The apparatus supplied for this method includes a scale whereby a definite image shift may be made, if that is desired by the operator. There is also a provision for a definite tube shift of either 10 or 15 cm. on the standard table and for the measurement of any tube shift, if the operator desires to make the shift of the image a definite amount—the procedure generally advised.

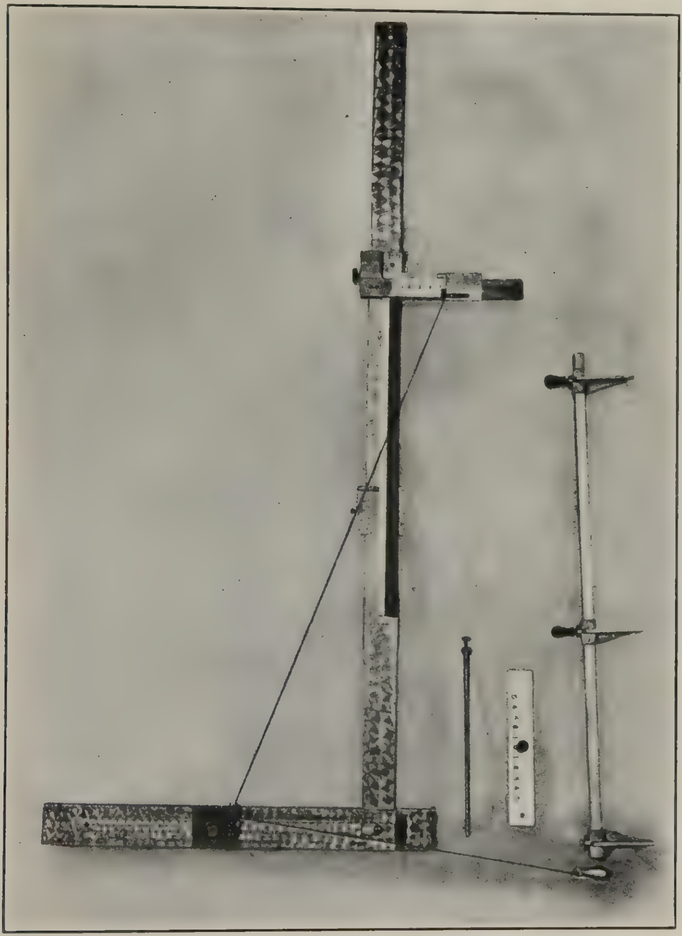

FIG. 126.—Apparatus shown in Figure 125

The complete equipment, including the reproducing device or wall meter and accessories, is shown in Figure 126.

The stereoscopic method is really a single-shift triangulation method. During the war the United States Army Medical Department perfected an apparatus devised by the late E. W. Caldwell, of New York, permitting stereoscopic fluoroscopy. This method, of course, requires special apparatus and the instrument is not yet generally upon the market. The stereoradiographic method is the procedure of choice when plates are made. In civil practice it is well to make stereoscopic plates in addition to the ordinary screen localizations.

DOUBLE-SHIFT FIXED-ANGLE METHOD

A number of single and double shift fixed-angle methods have been described, all, however, based upon the same principle. The method of Strohl,[24] professor of physics at the Sorbonne, is as follows:

At a convenient distance above the tube T (fig. 127), usually on the diaphragm of the tube holder, it is easy to fasten a piece of cardboard or aluminum to which are affixed two bits of straight wire, W^2 and W^3, placed parallel on either side of the midline W^1, so that the distance between the wires will bear a

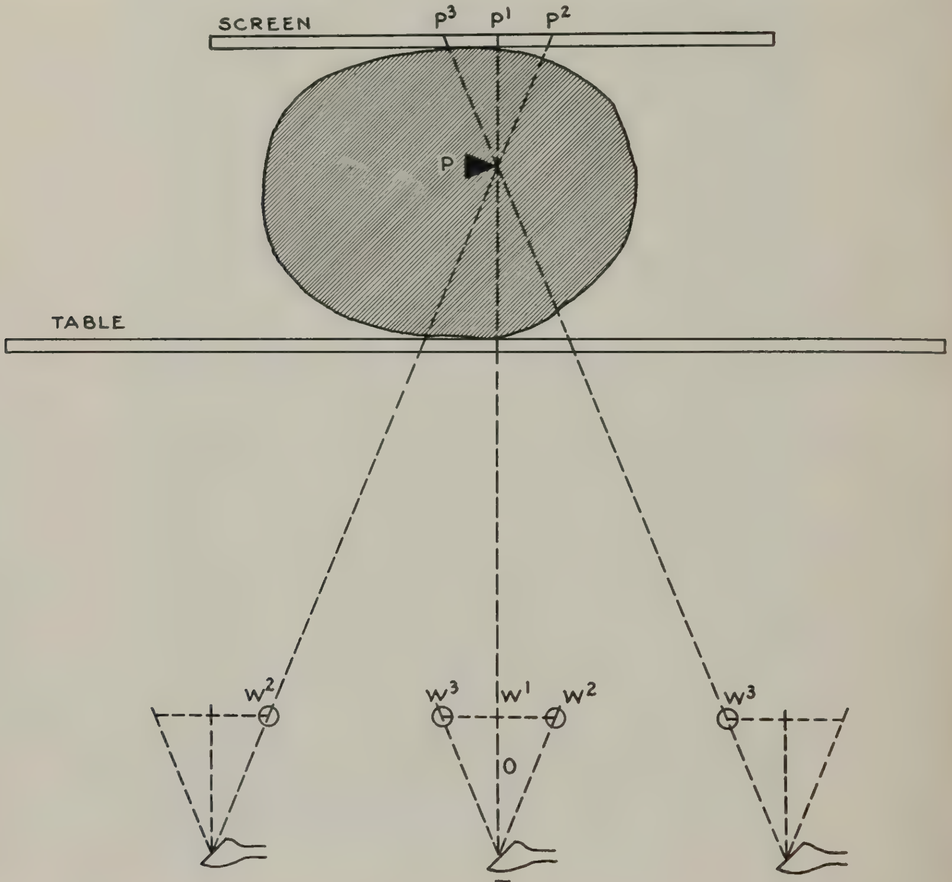

FIG. 127.—Method of similar triangles (double-shift, fixed-angle method)

fixed relation to the distance O from the cardboard or aluminum sheet to the focus of the tube. In other words, in the triangle TW^2W^3, the distance W^2W^3 bears a definite relation to the distance W^1T. For convenience, let us say that the two distances are equal and that W^2W^3 equals W^1T. If desired, a third wire may be added at W^1, coinciding with the normal ray. W^2W^1, therefore, equals W^3W^1. It is a geometrical fact that the distance between the shadows cast upon the screen by the wires W^2 and W^3 will, under these circumstances, always be equal to the distance from the screen to the focus point of the tube.

so long as the screen is held horizontal to the tube. With a small diaphragm opening the tube is brought directly beneath the foreign body P (fig. 127) and the position of the foreign body shadow marked upon the screen at P^1 and upon the skin directly underneath. The screen appearance at this moment is shown at *a* (fig. 128). Two leaves of the diaphragm are then opened widely making a slit and giving the appearance illustrated in Figure 128, *b;* the tube is then shifted to the left, during which movement the shadow of the right wire W^2 will also travel toward the left while the shadow of the projectile will travel toward the right, until a tube position will be reached where the two shadows coincide (fig. 128, *c*). This point is marked upon the screen with a grease pencil. The

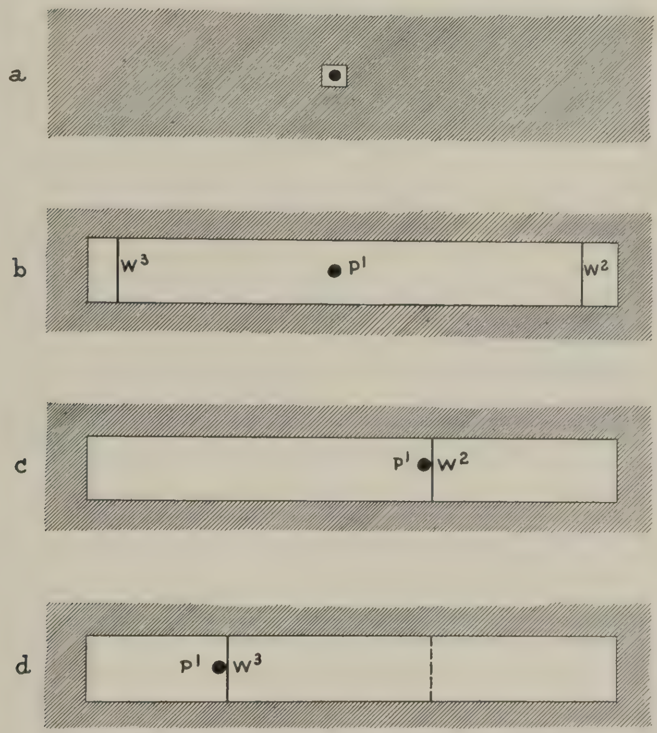

Fig. 128.—Screen appearance at different steps in the double-shift, fixed-angle method

tube is then shifted in the opposite direction until the shadow of the left wire, W^3, and of the projectile coincide (fig. 128, *d*). This point is also marked upon the screen with a grease pencil. According to the law of similar triangles, the distance between the two marks upon the screen equals the distance from the screen to the foreign body; and to estimate the depth of the foreign body it only remains to subtract the distance from the screen to the skin, if the screen itself does not rest directly upon the skin.

The distance between the wires W^2 and W^3 may bear any given relation to the distance from the focus point to the plane in which the wires are fixed. It is only necessary to know this relation in order to estimate the depth of the foreign body by this very rapid and accurate method. It is not necessary to

know the focus distance of the screen or the distance of the tube shift. The wires may be placed upon any of the ordinary types of fluoroscopic apparatus without interfering with the routine work; one must only know the ratio of the distance between the wires to their distance from the focus above referred to.

In place of the wires, which are sometimes somewhat hard to see through the denser portions of the body, one may file upon the two leaves of the diaphragm three notches (fig. 129), one directly above the focus of the centered tube, and one on either side of this central point at any given distance. The ratio may be varied, just as in the Strohl method. With the diaphragm closed, one has upon the screen, therefore, three diamond-shaped, illuminated notches (fig. 129); the two outermost notches correspond to the shadow of the two wires shown in Figure 128, *b*. The tube is shifted in the same manner, first to the left and then to the right until the foreign body shadow is brought to the center of each of the diamonds; these spots are marked upon the screen with a grease pencil, and the distance between them measured and translated into the depth of the foreign body.

During the war the so-called "26-degree method"—the distance from the middle notch to either of the outer notches being half the focus-diaphragm distance—was popular among French radiologists and was widely adopted by

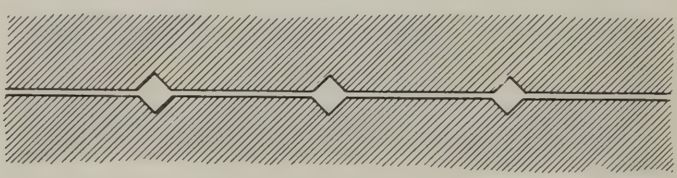

FIG. 129.—Screen appearance after notching the diaphragm leaves for the Roussel method

our own medical officers. With this method, only one shift was made from the central notch to one of the outer notches, and the distance of the shadow shift multiplied by two to determine the depth of the foreign body below the screen.

HARPOON METHOD

The harpooning method, the insertion of a sterile needle through the tissues to the foreign body, which serve as a guide to the surgeon in removing the projectile, requires no special apparatus not found in any hospital with a fluoroscopic X-ray equipment.

The instruments, the field of operation, and the surgeon's hands must be surgically clean, and a sterile sheet or towel must be held between the operative field and the fluoroscopic screen. By rotation and manipulation of the part the approximate anatomical position of the foreign body is determined as nearly as possible. The needle when introduced will mark out the line of the surgeon's approach; if the track of the needle is likely to pass near vital structures it is of importance that this line be determined in consultation with the surgeon. The path of attack having been determined and the surgeon having marked on the skin approximately where he wishes to make his incision, the part is rotated under the screen so that the skin mark will lie vertically over

the foreign body. A needle of proper length having been selected, it is seized with forceps and held at such an angle that the fingers of the operator will not be exposed to the rays. Under the fluoroscopic screen, the needle is pushed down upon the foreign body and left in situ.

This method has been modified and improved under the name of the "trocar and cannula method" by various surgeons of the allied armies. It should always be used under the direct supervision of a competent surgeon or of one who has the necessary anatomical knowledge and surgical judgment to use it without danger of infecting the patient or of injuring important structures. In cases with encapsulated foreign bodies the trocar and cannula method is often of great value, but it is not useful as a routine procedure in recent wounds, where the surgeon usually approaches the projectile or foreign body through the path by which it entered.

Under anesthesia, the skin should be punctured with a sharp scalpel, after which the cannula, with the obturator in place, is slowly passed into the tissues until it comes into contact with the projectile as determined by touch or by fluoroscopic observation at varying angles. After contact is secured, the obturator is removed and a piece of piano wire, bent at the lower end in the form of a fishhook, is passed well through the cannula. The latter is then withdrawn, leaving the piano wire hooked into the flesh. If necessary, the external end of the wire may be clipped with forceps or cut off short, and bent down close to the skin. The length of wire introduced beneath the skin indicates to the surgeon the depth of the foreign body. It is very important that the introduction of the needle or trocar should be carried out with the instrument in the line of the normal ray; any attempt to insert it at any angle will result in considerable mutilation of the tissues.

The harpooning method is not only a method of localization, but it is also a method of guidance for the surgeon during the operation of extraction.

HIRTZ COMPASS METHOD

The use of the Hirtz compass is foremost among the methods which serve to localize, and to guide the surgeon. This is an apparatus of which several types, all similar in principle, were employed during the war. For clinics where there are frequent extractions of foreign bodies from the cranium and from the deeper structures of the shoulders, axillæ, lumbar region, pelvis, and buttocks, this instrument can be highly recommended.

As originally proposed, this instrument was intended to be used in connection with radiographic work, whereby a permanent record should be made for the later setting of the compass, provided the identifying skin marks were not obliterated. On account of the very considerable time necessary to prepare a negative for examination and measurement, it has been found desirable in many cases to operate the compass by data secured from fluoroscopic examination, which is much more expeditious and, in many cases, will serve fully as well.

The essential feature of the Hirtz compass is the possibility of adjustment of the movable legs that support the instrument, so that when resting on fixed marks on the body of the patient the foreign body will be at the center of a

sphere, a meridian arc of which is carried by the compass. This arc is capable of adjustment in any position about a central axis. An indicating rod passes through a slider attached to the movable arc in such a way as to coincide in all positions with a radius of the sphere, and whether it actually reaches the center or not it is always directed toward that point. If its movement to the center of the sphere is obstructed by the body of the patient, the amount it lacks of reaching the center will be the depth of the projectile in the direction indicated by the pointer.

FIG. 130.—Hirtz compass guidance during a surgical operation

The value of the compass lies in its wide possibility as a surgical guide, in that it does not confine the attention of the surgeon to a single point marked on the skin, with a possible uncertainty as to the direction in which he should proceed in order to reach the projectile, but gives him a wide latitude of approach and explicit information as to depth in a direction of his own selection.

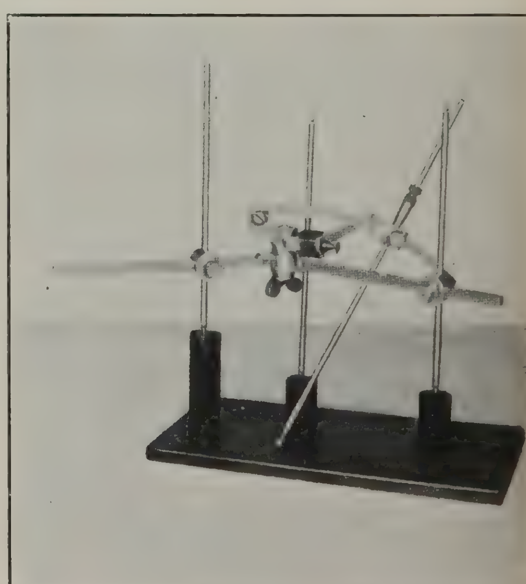

FIG. 131.—Hirtz compass

The compass is shown in Figure 131 and schematically in Figure 132. Three metal arms respectively labeled 1, 2, and 3 in clockwise rotation are so mounted as to turn freely upon a central pivot and have their upper surfaces all in a single plane. Each of these arms carries a slider, which may be adjusted to any position along the length of the arm. Each slider has an adjustable leg at right angles to the plane of the arms, that may be held in any position by a small thumbscrew. These legs are graduated and the zero point is not at either end of the legs, but a few centimeters below the upper portion, which terminates in a small knob. The center post about which the arms rotate has a hole at right angles to the plane of the arms and is also shaped to carry the curved metal arc, A. (fig. 132.) The hole in the slider on arc A, carrying the indicating rod, can be made to coincide with the opening through the center post.

When the legs are set at zero, quite irrespective of the position of the slider on the arms or of their angular position, and the compass stands on a plane surface, the indicating rod, passed through the slider on arc, A, will touch the supporting plane at the center of the sphere of which A is a meridian arc. A friction clip on the indicating rod may be adjusted in contact with the slider on A, and the distance from the lower end of this clip to the pointed end of the indicator will be the radius of the sphere of which A is an arc.

Figure 133 shows the compass with the legs shifted so that they no longer stand on the base plane, and, in fact, are at quite different heights; but the arc, A, and the arms of the compass have not been displaced, so that the pointer still reaches the center point, P, in this plane.

Figure 134 shows the compass actually set upon the body of a patient, its legs resting on three skin marks, M, N, and O, and with the indicating rod pointing toward the projectile, but failing to reach it because of contact with the skin of the patient at S. The depth of the projectile in this particular direction

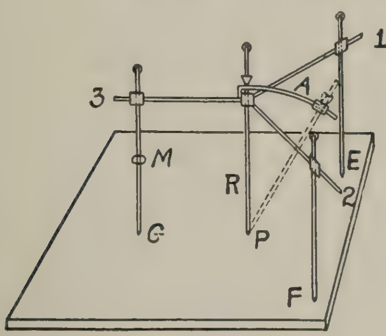

Fig. 132.—Schematic drawing of Hirtz compass with legs adjusted at zero points and resting on a plane

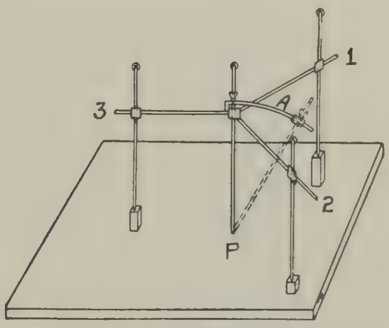

Fig. 133.—Arms and indicator of Hirtz compass. Same position as in Figure 132, but with legs elevated on blocks whose tops might correspond to skin markers

is indicated in Figure 134 by *d*. If, now, the indicating rod is placed in the slider carried by the arc, A, the rod touches the skin at a different point, S′, and the distance between the friction clamp on the rod and the upper surface of the slider on the arc, A, will be the depth of the foreign body along the direction indicated by the dotted line. It is evident from the construction that the surgeon may place the arc, A, in any position throughout 360°, and the slider at any position from the center to the extreme end of the arc, and still have the indicating rod point to the foreign body and show its depth from the point of contact with the skin. Figure 130 shows the compass in position on the patient at operation.

The exact amount which each leg of the compass must be shifted from its zero point in order to stand on the marker to which it belongs and yet have the indicating rod in the proper position is easiest seen in Figure 135, in which only a single leg of the compass is shown; but the same will apply to each of the legs in turn. Imagine a plane, parallel to the plane of the three arms of the compass, to be drawn through the projectile. The leg attached at arm number one

standing on the marker, M, would, if it could pass down to this plane, intersect the plane at the point, E, and under these circumstances, the indicator passing through the central post of the instrument would touch the skin at S, vertically above P. If the distance from the plane, from which measurements are made, to the lower plane, containing the projectile, is measured and, likewise, the distance MM′, it is seen that the amount by which this particular leg is raised from its zero point, where it would be set if it reached the point, E, will be the difference between the depth of the foreign body and the depth of the marker from any plane of measurement, for example, that of the fluoroscopic screen or a photographic plate. The fluoroscopic screen may be placed in any position parallel to the base plane, EP, and the difference, ME, would be quite independent of the height of the plane from which all measurements are made.

This may be summarized by saying that each rod is to be shifted from its zero point an amount equal to the difference between the depth of the projectile below the fluoroscopic screen, or other plane of reference, and the depth

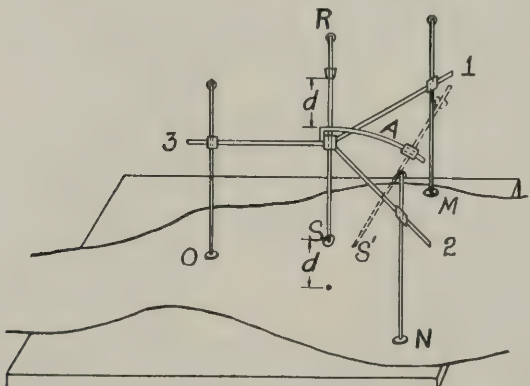

FIG. 134.—Schematic drawing of Hirtz compass set up on skin of patient

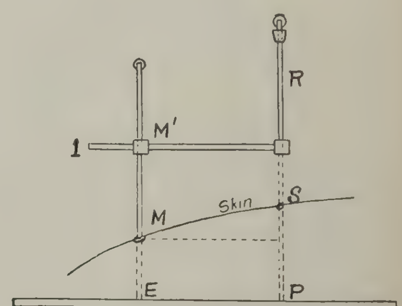

FIG. 135.—Reason for shift of leg of compass from zero point by the amount stated

of the skin mark upon which this particular leg would stand, measured from the same plane. It is absolutely essential in the use of the compass to adopt a systematic procedure, so that the arm to carry the leg is identified with the depth of measurement of its own skin point.

The data necessary to properly adjust the compass may now be stated by reference to Figures 132 and 135. The indicating rod in the central position and the three legs of the compass mark out, in any plane parallel to the base plane of Figure 132, four points of definite position in the plane. Any vertical shift of the legs will still allow them to retain their position in lines passing through the points, E, F, G, and P. The point G, Figure 132, is then in a vertical line passing through the marker, M, and the data necessary to set the compass must give the position in a plane of these four points, and in addition to this must give the depth from a fixed plane, parallel to the base plane, EFG, of the three markers on the skin of the patient and of the projectile within the patient's body. Whether this data is to be found by a photographic or a fluoroscopic process is immaterial, as the steps in its use will be identical.

When a fluoroscopic method is to be used, an auxiliary device may be found of considerable aid in rapidly and accurately securing the requisite data. Such a device is shown at A, Figure 136, and consists of three arms, each with a slider very similar to the original compass. In fact the latter may be used with rather less convenience by removing arc, A, and allowing the indicating rod to project a short distance below the center, with the legs temporarily removed. The auxiliary compass has its arms numbered in the same way as the original Hirtz compass and has a projecting pin which fits the perforation in the screen. One of the arms is rigidly attached to a ring concentric with the axis of rotation about the pin, while the other two are movable, but may be clamped by thumb nuts to the ring. It is evident that placing the perforation in the screen in the vertical ray passing through the projectile definitely fixes the position of the center post. If, then, each marker in turn is brought into

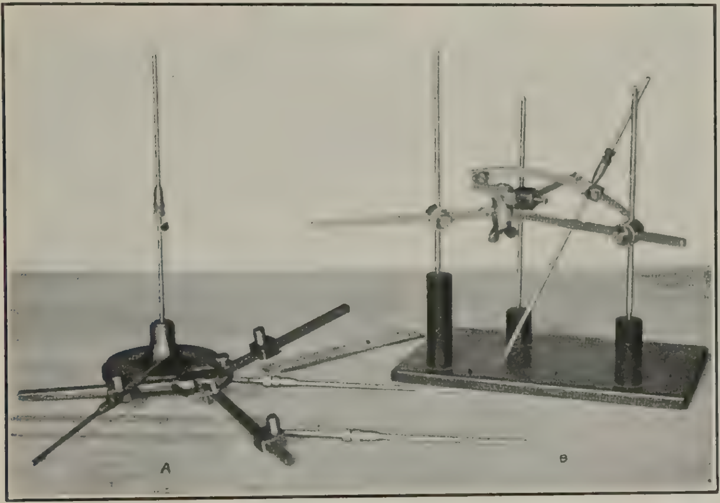

Fig. 136.—Accessory apparatus for fluoroscopic work with Hirtz compass. A, Auxiliary compass, pedestal support, and three markers with friction clips; B, Hirtz compass mounted with the three legs at different levels, so that a pointer reaches white spot on the base plane at the center of the sphere of which the curved arc is a part

the vertical ray and the arm and slider adjusted so that the hole in the slider matches such a projection of each marker, the three openings in the sliders and the central pin fix the four points which it is necessary to obtain. It then remains to determine the depth of the projectile, for which one of the methods, A, B, or C, should be employed and also to determine the distance from the screen to the opaque markers. When using the fluoroscopic method, the latter depth can be very readily determined by simply passing a suitable measuring rod through the perforated screen, which has been brought into the vertical ray passing through the marker. This depth is to be recorded and accurately identified with the arm carrying the slider corresponding to that particular skin marker. In order to facilitate this measurement a set of three measuring rods with friction clips, differing slightly in shape, are provided. As soon as these four depths and the four marks in the plane of the screen have been

determined, the work of the roentgenologist is completed, provided he has made sure that the skin marks are plainly visible. The adjustment of the compass may then be carried out by an assistant to either the roentgenologist or the surgeon, after which the instrument can be sterilized and is ready for the surgeon's use.

FLUOROSCOPIC METHOD, WITH AUXILIARY COMPASS

Find the shadow of the projectile, P_o, on the screen, and reduce the size of the diaphragm, keeping the shadow in the center of the illuminated area. Adjust the screen so that the opening at the center of the screen coincides with the center of the shadow, lock screen carriage in this position for all except vertical travel. Mark the skin through the opening by use of the special marker provided. Determine the depth of the projectile by either method A. or C. Raise the screen and attach three metallic markers (preferably three small washers) to the skin at suitable points, and mark the skin at each point selected. Choose skin points with care to ensure: No interference with probable incision; proper stability of the compass; as firm foot points as possible. Lower the screen near to or touching the skin, with the central hole still in the vertical ray through the projectile, and insert the pin of the auxiliary compass in the hole. Be sure that the screen is locked in position. Bring arm marked 1 to point toward the operator's right and loosen thumb nuts on arms 2 and 3. Shift the tube to bring the right-hand marker in the vertical ray (leaving screen locked), and adjust the slider on arm No. 1 so that its opening coincides with the projection of the marker, Figure 137. If washers are used the round opening is easily identified. Do the same with each of the other two markers, insuring that No. 1 does not move when adjusting the others (a small clamp will aid in this) and lock each arm. The central pin and the three sliders then give the positions for the arms and sliders of the compass. Remove the auxiliary compass and determine the depth of M, N, and O below the upper surface of

FIG. 137.—Method of showing fluoroscopic adapter with Hirtz compass

the glass on the screen. For the depths of M, N, and O use the small rods provided with friction sliders and make the measurement by passing the rod through the perforation in the screen, which, for this purpose, is to be brought vertically over each marker in turn. If the friction clips are then pushed down until they touch the glass and are properly adjusted as to friction, the distance from the clips to the end of the rod will indicate the depth desired. These sliding clips are shaped to correspond to the projecting blocks on the sliders of the auxiliary compass, and care must be taken to use them in their proper places, so that there is a complete identification of the compass slider and the depth of the marker corresponding. Form the habit of using these in a definite order, during these depth measurements, to minimize chances of error. If no further fluoroscopic work is to be done these depths may be determined in daylight. Otherwise use the vertical ray from the tube.

Setting the Hirtz Compass

By use of the auxiliary compass.—(1) Remove the arc and the indicator rod; lower the three legs until the upper (rounded) ends project 1 to 2 cm. (2) Lay the auxiliary compass on a flat surface with the center pin upward. Invert the Hirtz compass and place the central hole on the pin of the auxiliary. Unlock wing nut at center of compass, thus releasing the arms; bring arm No. 1 and its slider to such a position that on loosening leg No. 1, it will drop into hole of the No. 1 slider of the auxiliary. Tighten set screws of slider and of leg No. 1 (fig. 138). Proceed in the same manner with arms, sliders, and legs Nos. 2 and 3. Tighten wing nut at center of Hirtz compass, thus locking compass arms. (3) If pedestal support is provided, set the lock sleeve on the vertical rod, so that when the pedestal stands on a flat surface, and the Hirtz compass is placed thereon, with the pedestal rod through the central hole of the compass, it will be supported in such a position that the legs will drop to their zero points when loosened, leaving the compass supported on the pedestal. (4) Shift each leg an amount equal to the difference between the depth of the projectile and the depth of the skin marker on which each individual leg is to stand. (Leg No. 1 stands on skin marker No. 1, etc.) Tighten each leg,

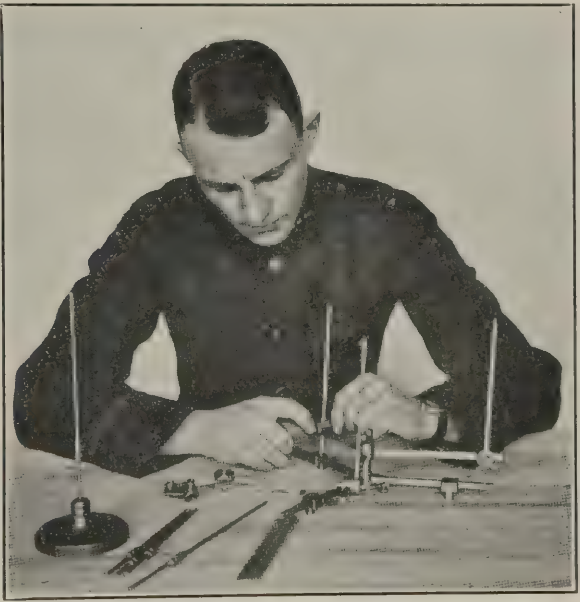

Fig. 138.—Setting arms and legs of Hirtz compass directly from the auxiliary compass

replace compass arc and indicating rod, the latter with lock sleeve properly set, and the compass is ready for sterilization and use by the surgeon.[a]

It is recommended that even if the compass is to be immediately set direct from the auxiliary a record of the data necessary for setting be made and retained until after the operation.

From the diagram of data.—(1) The auxiliary, having been set to mark shadows on the screen, is placed on a plain sheet of paper with center pin down. Indicate with a pen the spot on the paper where the pin touches and mark it P_0 (being directly over the projectile)—a small drawing board with a hole in the center, in which the pin may be inserted through the record paper, may be helpful. Indicate the locations of the holes in sliders 1, 2, and 3, thus giving their relations to P_0; identify each by number and write opposite each the depth in centimeters to the skin below the fluoroscopic screen. The depth of P_0 below screen must be similarly indicated. (2) Take the Hirtz compass with indicating rod inserted in central hole, and set point of indicating rod on P_0 of diagram. Loosen wing nut at compass center, thus releasing arms; bring leg No. 1 to stand on mark No. 1 of diagram. Proceed identically with legs Nos. 2 and 3; then, with indicating rod and the three legs accurately on the proper points of diagram, tighten wing nut to lock compass. Tighten all set screws. (3) Place the compass on pedestal support and proceed as indicated in paragraph 4 above. The instrument is now ready for sterilization and use by the surgeon. Care must be taken to avoid handling the compass in any manner that would displace any of the settings. In case of deferred operation, the four skin marks should be tattooed, or they must be renewed with sufficient frequency to insure their identification at time of operation. If metal washers are used, they may be sterilized and attached at the time of the operation; they serve very well to hold the compass legs on their proper skin points.

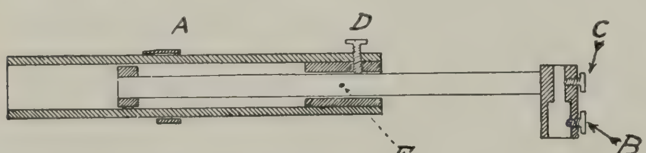

FIG. 139.—Detail of holder for direct setting of Hirtz compass

Direct setting of the Hirtz compass.—Several devices for holding the Hirtz compass in order to make a direct adjustment of the foot points and leg heights on the patient have been proposed. This method possesses two distinct advantages: It may be done quite expeditiously; it indicates clearly to the operator how the compass is going to stand on the patient when in use. Its disadvantages are: The necessity of considerable illumination in the fluoroscopic room when placing the compass; danger of movement of the patient between localization and final adjustment; need for the compass both in the fluoroscopic rooms and in the operating room.

In order to adapt this method to the standard table, the design shown in Figure 139 has been developed. This consists of a tube fitting into the socket of the screen carrier, holding a square sliding rod with an end socket taking the hub of the compass.

[a] This subtraction can conveniently be made by laying off on paper the distance from the top of the lead glass on the screen to P, then, placing auxiliary rod No. 1 with its sleeve indicating the skin depth for marker No. 1, mark this distance on the line previously made, and reset the sleeve to the length remaining on the projectile depth line.

The collar, A, on the tube has a V-shaped projection intended to fit a notch in the carrier socket so as to prevent rotation from a definitely determined position.

The fundamental principles in this method are the alignment of the central axis of the compass with the vertical ray through the projectile, and the bringing of the compass to the proper height so that the top of the slider on the arc, when in its central position, is at a distance from the projectile equal to the radius of the arc.

In order to secure the former, the holder should enable us to readily make the plane of the arms level. Then the compass should be allowed to move up or down in a vertical direction without rotation. When the indicator is placed in the central position and the compass is properly placed on the patient, the radius mark on the pointer will be as far above the arc slider, through which the pointer is inserted, as the measured depth of the projectile along the vertical ray. While rigidly held in this position the arms and legs may be adjusted at will to support the compass in this position. (Fig. 140.)

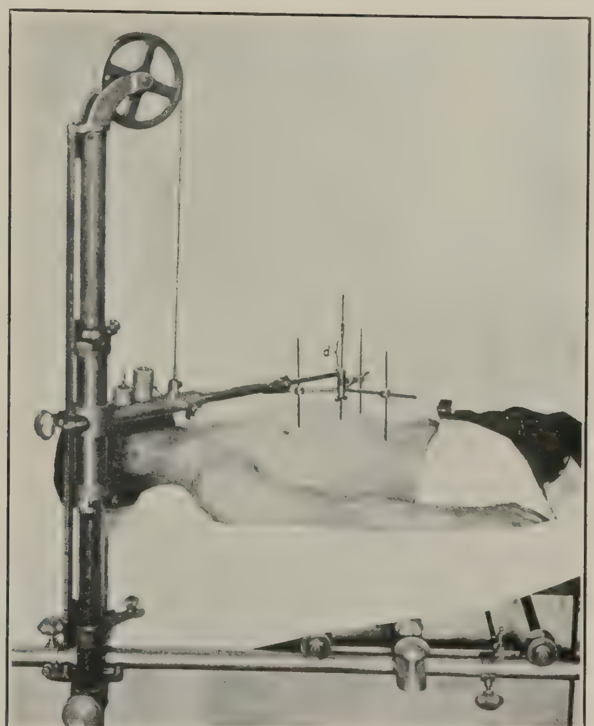

Fig. 140.—Direct setting of Hirtz compass. Compass and holder in position

Care must be taken to insure that the patient does not move between the localization and the completion of the adjustment; that the pointer is raised from its zero the correct distance; that all parts of the compass are locked before removal from the body. The holder must be adjusted before it is used the first time as follows: Remove screen-holding rod from the horizontal socket and insert holder. Remove arc from the compass, insert hub in the holder, and place two of the arms close together so that the line of the holder bisects the angle between them. Then lock the center arm clamp. Place a small level on the two arms perpendicular to the holder rod, and rotate rod until this shows level, then clamp by socket set-screws. Make a scratch mark where the V on the ring comes in contact with the socket. Remove the holder and file a small notch with a triangular file to take the V on the collar. Test out as to level, when the holder is replaced in the socket with the V engaging the notch. If not quite correct, loosen the set-screws at the end where the square rod enters, rotate to level, and fasten firmly.

The above steps need to be done only once and the following procedure for use is then quite simple: Remove arc from the compass and insert in the holder, fastening with the thumb nut, B. Set the sliding clamp on the indicator rod at the ring mark; i. e., so that the distance from the lower end of the slider to the pointed end of the indicator is the radius of the arc. Insert indicator in the compass holder and raise until the distance from the top of the brass holder to the lower end of the sliding clamp is the projectile depth below the skin mark. Fasten by nut C. Raise the legs of the compass and adjust the holder until the lower end of the pointer rests on the skin mark. Lock carrier in position. Place arms and feet as desired so that the latter rest on as firm skin points as possible, and clamp all parts of the compass. Raise compass slightly by the vertical movement of the carrier, mark skin points for the feet, and identify them clearly. This method is much more convenient than to mark the skin first and then adjust the compass to fit the marks. Remove compass, read and record height settings of legs, then record position of foot points, and center for resting the compass later if it should be necessary. For use in the operating room the compass may be sterilized by a flame.

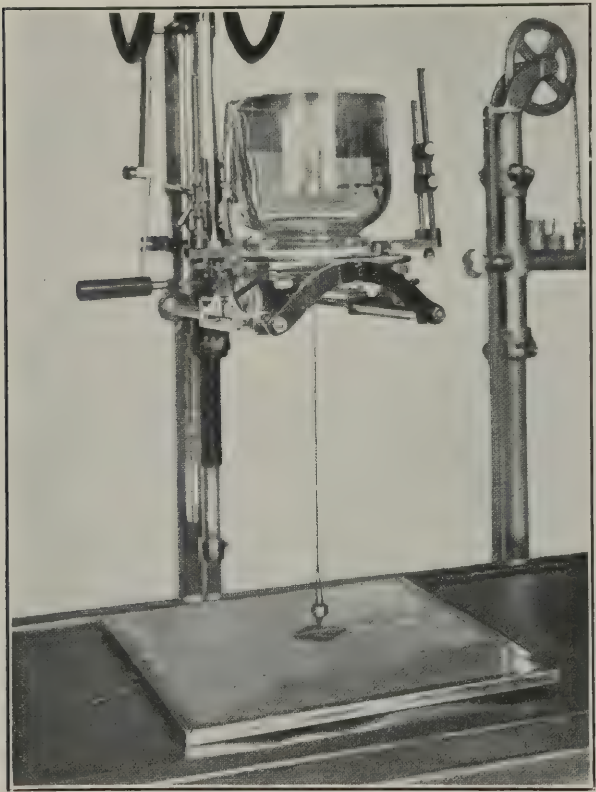

FIG. 141.—Centering of tube above plate holder on cassette with small cross wires, photographic method, Hirtz compass

USE OF THE HIRTZ COMPASS WITH PLATES

When it is desired to establish the data necessary for the use of the compass with photographic plates or films, it is necessary that two exposures be made from two different target positions, either upon a single plate, or upon two separate plates or films, without movement of the patient or skin markers. The latter method is usually preferred.

There is furnished for this work a small, flat square of celluloid into which are inserted two small steel wires forming a right-angled cross. The celluloid has two holes punched in diagonally opposite corners, through which a tape may be passed, and this is to be tied around the tunnel plate changer so as to fix the desired centering mark, when two plates or two films are to be used.

Figure 141 shows how the tube is centered, using a plumb line to secure exact position. This must be done before the patient is placed in position, and care must be taken not to disturb the adjustment.

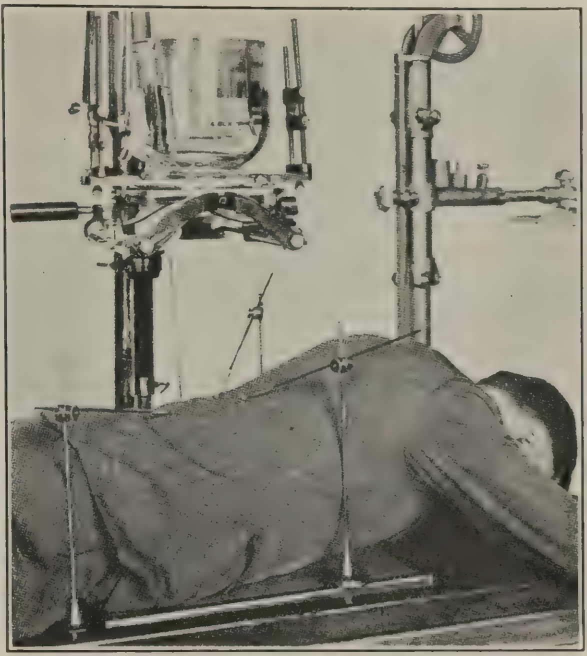

Fig. 142.—Skin markers, plate holder, and tube holder in position for photographic method, Hirtz compass

Figure 142 shows the tube, patient, and markers in position for one of these exposures. One should not forget to attach to the plate tunnel the marking device or to use the three metallic markers in contact with the patient's skin at points properly chosen and marked for identification.

The principle of the method is shown in Figure 143. A small marker, X, is placed approximately at the center of the plate, if one plate is to be used, or on top of the plate changing tunnel, if two plates are to be exposed. Let CX be a perpendicular erected to the plane of the plate at the point X and extending upward a distance of 60 cm. Let F_1F_2 be positions of the focus in a line parallel to the plane of the plate at the level C, and assume that CF_1 and CF_2 are each three centimeters in length. Suppose that M is one of the markers on the patient's body. When an exposure is made with the target at F_1, the shadow of M will fall on the plate at M_1 and, when an exposure is made from the position F_2, the corresponding shadow will be M_2. Had the exposure been continuous during the motion of the target from F_1 to F_2, there would have been found on the plate a straight line of shadows connecting M_1 and M_2. If we drop perpendiculars from the two focal positions to the plane of the plate, intersecting it at the points F'_1F_2, we see that $F'_1F_1M_1$ is a plane perpendicular to the plate and passes through M_1, and the trace of this plane upon the plate is F_1M_1.

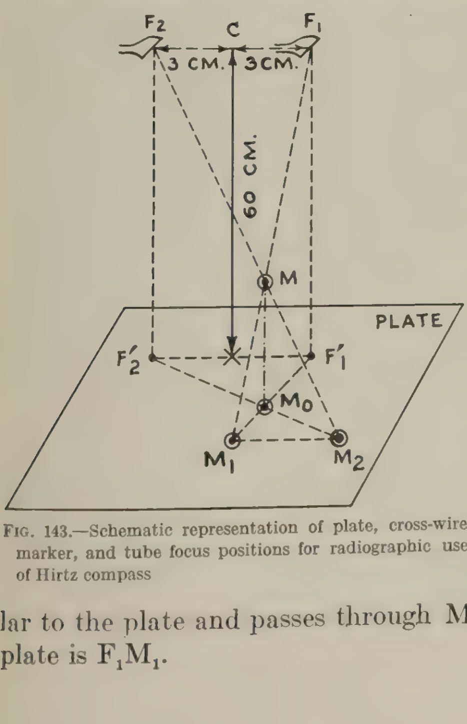

Fig. 143.—Schematic representation of plate, cross-wire marker, and tube focus positions for radiographic use of Hirtz compass

In the same way a plane passed through $F_2F'_2M_2$ will be perpendicular to the plate and its trace will be F'_2M_2. It follows from geometry that the intersecting line of these two planes, MM_0, will be a line passing through the point M and perpendicular to the plate. Consequently M_0 is the foot point of this marker on the plate to be used in the compass adjustment. Also the lines M_1M_2, $F'_1F'_2$ and F_1F_2 are parallel.

Figure 144 shows part of a developed negative upon which there appears a shadow at M_1, a shadow at M_2 and a single image of the marker on the plate—a single image, since its motion is zero or nearly so, the marker being most in contact with the plate itself. If one joins M_1 and M_2 by a straight line and then draws through the center of the cross a line parallel to M_1M_2 and measures a three centimeter length on this line through X in each direction from the center of the cross, the points so determined will be F_1 and F_2 of Figure 143. Cross connection between the ends of these lines, that is F'_2M_2 and F'_1M_1 then definitely locates the point M which will be the foot point sought.

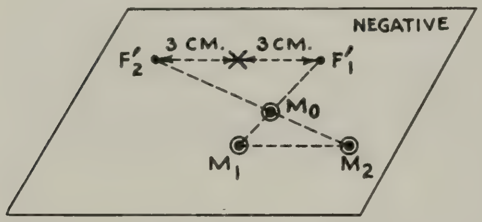

FIG. 144.—Construction for finding one of the foot points M from the shadows of a corresponding marker as shown at M_1 and M_2, and the shadow of the cross marker X

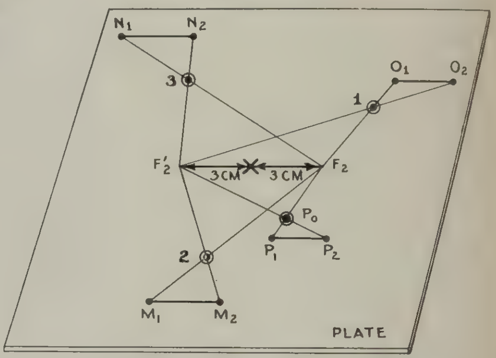

FIG. 145.—Complete chart for setting feet of Hirtz compass

The length of the line M_1M_2 will clearly decrease as M is placed nearer the plate, and increases as it is raised. For the definite 60-cm. target-plate distance and 6-cm. tube shift there corresponds one height MM_0 for one image shift M_1M_2. These relative values are shown in Table 26 in which all measurements are given in centimeters or tenths of centimeters.

Figure 145 shows a full construction and necessary record derived from the photographic plate used in setting the compass. This data is used exactly as was that derived from fluoroscopic examination.

It will require a considerable amount of skill and judgment to so place the markers on the patient's skin as to give reliable readings and at the same time furnish proper support for the compass. These data are used exactly as were those derived from flúoroscopic examination.

It will require a considerable amount of skill and judgment to so place the markers on the patient's skin as to give reliable readings and at the same time furnish proper support for the compass when used at operation. Especially one must insure that the shadows of all the markers fall on the photographic plate. It is also clearly undesirable to have the lines whose crossings are to indicate foot points for the compass setting too nearly parallel, as in that case a slight error in their location may bring a decidedly large shift in the position

of foot points. Transparent celluloid scales are sometimes furnished, which assist somewhat in determining whether the shadow of the markers will fall on the plate.

Knowing approximately, by previous fluoroscopic or other examination, the position of the projectile whose localization is sought, select a plate changer of proper size, attach the cross, and place on the table in the position to which it is to be used.

By means of a plumb bob, adjust the tube stand so that the central position of the target shall be vertically over the metallic cross, and be sure that the distance CX, Figure 143, is 60 cm. Adjust stops to allow the tube to move 3 cm. in each direction from the central point.

Place the patient on the tunnel plate changer, taking care that the cross, plate changer, and tube are not displaced in the process. Or, if the tube holder is rotated, fix stop for its exact return. Make sure that the tube is three centimeters from its center point and insert a plate. Place the three skin markers in the desired position. The balls as furnished with the apparatus may be used, or small metallic markers, preferably V-shaped, may be attached to the patient's skin with small pieces of adhesive. Make the exposure needed. Remove the first plate, shift the tube, and make the second exposure. Do not attempt to get the data from the plate or film until it is dry. If it is once scratched or smeared, it will be impossible later to get good measurement.

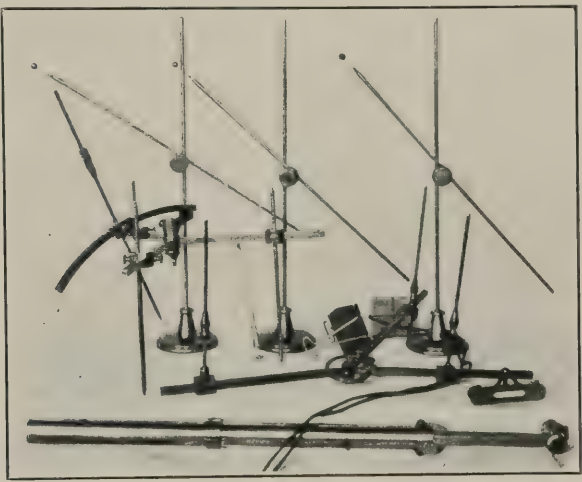

FIG. 146.—Equipment supplied for use with Hirtz compass

If the exposures are to be made on a single plate, be sure not to overexpose. When using two plates, the image of the cross is used to superimpose the plates and to transfer the data to the record sheet.

Make the record described above, locating the foot points and the center points. Read M_1M_2, N_1N_2, O_1O_2, and P_1P_2, in centimeters and fractions, enter these on the record under column marked spread, and enter under height the corresponding number in Table 26. Thus:

	Spread	Height	Shift	
	Cm.	*Cm.*	*Cm.*	
M_1M_2	1.5	12	6.6	$P_1P_2-M_1M_2$
N_1N_2	2.1	15.5	3.1	$P_1P_2-N_1N_2$
O_1O_2	3.6	22.5	3.9	$P_1P_2-O_1O_2$
P_1P_2	2.7	18.6		

The equipment supplied for use in method E is shown in Figure 146.

TABLE 26.—*Measurements for use in connection with Hirtz compass*

[Focus plate distance, 60 cm.; tube shift, 6]

Spreading	Height	Spreading	Height	Spreading	Height	Spreading	Height	Spreading	Height	Spreading	Height
cm.	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*
0.1	1.0	.95	8.2	1.8	13.85	2.65	18.4	3.5	22.1	4.35	25.2
.15	1.45	1.0	8.55	1.85	14.15	2.7	18.6	3.55	22.3	4.4	25.4
.2	1.95	1.05	8.95	1.9	14.45	2.75	18.85	3.6	22.5	4.45	25.55
.25	2.4	1.1	9.3	1.95	14.7	2.8	19.1	3.65	22.7	4.5	25.7
.3	2.85	1.15	9.65	2.0	15.0	2.85	19.3	3.7	22.9	4.55	25.85
.35	3.3	1.2	10.0	2.05	15.3	2.9	19.55	3.75	23.05	4.6	26.05
.4	3.75	1.25	10.35	2.1	15.5	2.95	19.8	3.8	23.25	4.65	26.2
.45	4.2	1.3	10.7	2.15	15.85	3.0	20.0	3.85	23.45	4.7	26.35
.5	4.6	1.35	11.0	2.2	16.1	3.05	20.2	3.9	23.65	4.75	26.5
.55	5.05	1.4	11.35	2.25	16.35	3.1	20.45	3.95	23.8	4.8	26.65
.6	5.45	1.45	11.7	2.3	16.65	3.15	20.65	4.0	24.0	4.85	26.8
.65	5.85	1.5	12.0	2.35	16.9	3.2	20.85	4.05	24.2	4.9	26.95
.7	6.25	1.55	12.3	2.4	17.15	3.25	21.1	4.1	24.35	4.95	27.1
.75	6.65	1.6	12.65	2.45	17.4	3.3	21.3	4.15	24.55	5.0	27.25
.8	7.05	1.65	12.95	2.5	17.65	3.35	21.5	4.2	24.7		
.85	7.45	1.7	13.25	2.55	17.9	3.4	21.7	4.25	24.9		
.9	7.85	1.75	13.55	2.6	18.15	3.45	21.9	4.3	25.05		

The advantages of the Hirtz compass in selected cases are numerous. After the sterilized compass has been placed in position, the penetration needle, when brought in contact with the skin, indicates the point where the incision should be made, and the depth and the direction in which the foreign body lies. By means of the rotating device through which the penetration needle is passed, the surgeon can select the point of entry without in any way embarrassing the usefulness of the instrument. The instrument, being sterile, can be re-applied as often as needed during the operation.

In using the compass, it is important that the skin marks selected for the compass legs should constitute a large triangle and that these marks should not be covered by drapes or towels during the operation. When the compass is being set, the patient should lie in either the prone or the supine position rather than on the side, and at operation exactly the same attitude should be assumed. It is important that the muscles be relaxed as far as possible; otherwise muscular contraction maintained during the X-ray examination is likely to disappear during anesthesia and thus possibly alter the position of the projectile to a considerable degree. Duval[25] cites a case in which a bullet located in the adductors of the thigh shifted eight centimeters when the contracted muscles were relaxed.

DEPTH OF ANATOMICAL LANDMARKS BENEATH THE SKIN

The table given below is of value in determining the exact position of a foreign body in relation to points on the skeleton. In their article published in connection with this table, the authors state that the surgeon often experiences many difficulties when operating for the removal of a foreign body even after the roentgenologist has made an accurate localization.[26] Previous to the war, the surgeon studied the ultimate depth of his operation only with regard to certain surrounding anatomical landmarks, and not in terms of centimeters or inches beneath a point on the skin. If the roentgenologist reports a projectile as being 4.5 cm. from a point on the skin of the back overlying the transverse process of the 12th dorsal vertebra, the surgeon has little knowledge as

to where this depth will lead him. If, however, the surgeon knows that the average depth of this structure is less than 4 cm. from the skin, he appreciates the fact that the projectile must lie in or just anterior to the transverse process. The objection is, of course, that individuals vary greatly in thickness of various parts, but the authors call attention to the fact that the soldier is selected after rigid examination and, as a result, the extremely thin and extremely obese are not present.

TABLE 27.—*Depth of anatomical landmarks*

Incision	Depth of anatomical position	
Head, laterally:	*Cm.*	
Just above zygoma	2.5	To sphenosquamosal suture.
Just below zygoma	4.0	To sphenoidal bone.
To coronoid process or condyle of mandible	2.5	
Neck:		
Anteroposteriorly—		
Through center of larynx	5.0	To body of vertebra.
3 cm. to side of center of larynx	4.0	To transverse process of cervical vertebra.
3 cm. to side of center of larynx	7.5	Total depth of neck.
Through middle line of trachea just below caricoid	4.0	To body of vertebra.
3 cm. to side of center of trachea	4.0	To transverse process of vertebra.
From center of suprasternal notch	3.0	To posterior border of manubrium.
Laterally—		
From center of middle of neck	4.0	To tranverse process of vertebra.
From center of middle of neck	6.0	To body of vertebra.
From just below tip of mastoid process	6.0	To body of first cervical.
Chest:		
Superiorly—		
From a point midway between root of neck and tip of acromion.	5.0	To apex of pleura, downwards.
From a point midway between internal and external extremities and just behind posterior border of the clavicle.	5.0	Do.
Anteriorly—		
From center of lower border of clavicle backwards to subscapular fossa just clear of ribs.	7.5	
From a point just over tip of coracoid to subscapular fossa backwards.	7.5	
From a point 2.5 cm. external to sterno-clavicular joint just below clavicle.	3.5	To first rib.
From a point 2.5 cm. external to sterno-clavicular joint just below clavicle.	2.0	To pleura.
From a point 5 cm. external to sterno-clavicular joint just below clavicle backwards.	3.0	To first rib
From a point 5 cm. external to sterno-clavicular joint just below clavicle backwards.	4.5	To pleura.
From a point 5 cm. below center of clavicle	5.0	Do.
Posteriorly—		
To supraspinous fossa	2.5	
To intraspinous fossa	2.0	
To transverse process of seventh cervical vertebra	4.0	
To pleura level of seventh cervical vertebra	5.0	
To anterior level of body of seventh cervical	7.5	
To transverse process of twelfth dorsal vertebra	3.5	
To pleura level of twelfth dorsal vertebra	5.0	
To anterior level of body of twelfth dorsal vertebra	8.5	
Abdomen:		
Thickness of wall from front—		
1 cm. to either side of middle line just above umbilicus	2.5	
1 cm. to either side of middle line just below umbilicus	3.0	
Just internal to anterior superior spine to iliac fossa	7.5	
Midway between anterior superior spine and pubic crest to front of acetabulum.	5.0	
Thickness of wall from side—		
On level of tip of twelfth rib in line upwards from anterior superior spine.	2.5	
Thickness of wall from back—		
To transverse process third lumbar	4.5	
To anterior level of body of third lumbar	11.0	
To anterior level of psoas muscle	13.0	
Hip and thigh from front:		
8 cm. below anterior superior spine to head of femur	6.0	
8 cm. below anterior superior spine to neck of femur	5–7.0	
15 cm. below anterior superior spine (level of lesser trochanter) to front of femur.	4.0	
To greater trochanter	11.0	
To lesser trochanter	9.0	
Brim of pelvis 2.5 cm. in front of sacroiliac synchondrosis	9.5	
To anterior inferior spine	3.0	

TABLE 27.—*Depth of anatomical landmarks*—Continued

Incision	Depth of anatomical position
Hip and thigh from front—Continued	*Cm.*
To spine of ischium	12.5
To anterior surface of line of junction of ascending ramus of ischium and descending of pubis.	7.0
To ischial tuberosity	13.0
Hip and thigh from back:	
To ischial tuberosity	6.0
To spine of sacrum on level of posterior superior spines of ilia	3.0
To sacral groove	5.0
To head of femur	5.0
To greater trochanter	9.0
To lesser trochanter	7.5
To brim of pelvis 25 cm. in front of sacroiliac synchondrosis	10.0
To anterior inferior spine	15.0
To spine of ischium	5.0
To posterior surface of junction of ascending ramus of ischium and descending ramus of pubis.	11.0

EYE LOCALIZATION

In the case of foreign bodies in the eye, very accurate localization is necessary, as knowledge of the exact position of the foreign body may mean the saving of an eye or the preservation of vision.

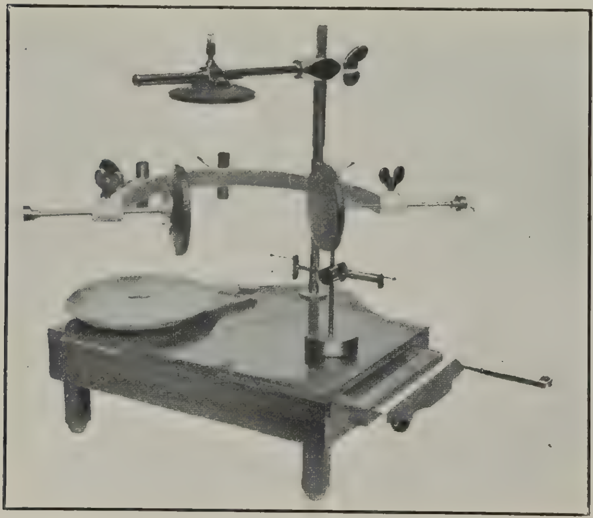

FIG. 147.—Headrest for use with the eye localizer

The simple Sweet-Bowen apparatus consists of two general parts—the base or headrest, as illustrated in Figure 147 and the localizer, as shown in outline drawing, Figure 148.

The headrest base is composed of the following parts: A plate-slide tunnel, so constructed as to protect one-half of a 5 by 7 photographic plate while the other half is being exposed, and to protect the exposed half while the second exposure is being made. Four rubber-tipped legs to raise the tunnel so that it will act as a pillow to hold the patient's head level when lying on his side. A plate holder having a slide that will protect the plate from the ordinary light, but offer no resistance to the X ray. An arm or handle attached to the plate-holding slide to enable the operator to shift the plate the correct distance for each exposure, and to withdraw the same when both exposures have been made. A pneumatic cushion for the comfort of the patient. A double clamp to hold the patient's head and to prevent any horizontal movement. A single vertical clamp to press the head downward upon the pneumatic cushion. The localizer consists of a heavy metal base, Figure 148; an upright standard, B, to support the localizer and permit the

same to be adjusted and held firmly at any desired height. The indicator ball D, with its needle-supporting item D^2, which, when properly adjusted to the center of an eye, will cast its shadow on the photographic plate and serve as a landmark to indicate the center of the cornea.

The metal tip E, of stem E^2 is made cone shaped, so as to more easily differentiate its shadow from that of ball D. These indicators are permanently adjusted a known distance apart (15 mm.), and the base of the localizer is provided with two holes exactly 15 mm. from center to center, which should be employed to verify this adjustment in case of doubt. When an X-ray plate is made of them obliquely, adjusted to an eye as above stated and as indicated in "front view" on the chart, we are enabled by their shadows to definitely locate the source and course of the rays of light (in relation to the chart) that caused the shadows. Also, the position of any foreign body that may show on the same plate can very easily be determined by the position of its shadow in relation to that of the ball and cone, because the exact position of the latter with reference to the chart is known and indicated (front view).

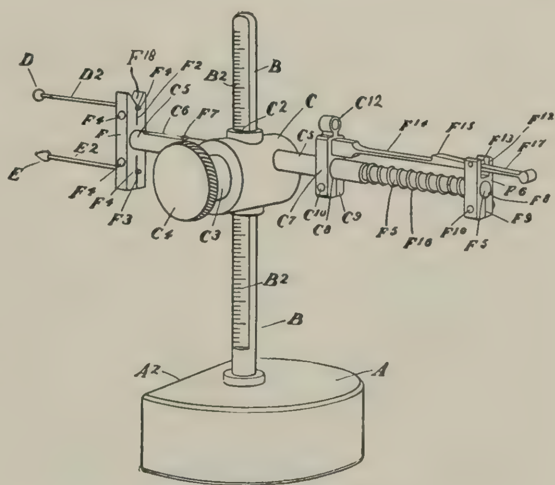

Fig. 148.—Sweet eye localizer

Tube C^{12} and notch F^{18} are sights similar to those used on a rifle, with which the operator can accurately align the center of the cornea of the afflicted eye with ball D and its supporting step $D.^2$ F^{14} is a spring trigger which presses upwards against pin $F.^{13}$ F^5 is the end of the rod to which the indicator-ball and cones D and E are attached by bracket F, the whole being supported by passing through tube $C.^5$ Spring F^{14} being attached to stationary tube C^5 by means of bracket $C,^7$ rod F^5 with bracket F^6 can be pressed forward until pin F^{13} is engaged by notch $F.^{15}$

By loosening set screw C^4 the bracket C can be raised or lowered until ball D, with its supporting stem $D,^2$ is in exact alignment with the center of the cornea of the affected eye, and the screw is then tightened.

The patient is instructed to close his eyes, and the entire instrument, with its base, is slid forward until indicator ball D presses into the eyelid approximately its thickness. The trigger F^{17} is then depressed to disengage notch F^{15} from pin F^{13}, when spring F^{16} will cause the rod F^5 and indicator-ball D and cone E to rebound exactly 10 mm., being restricted by knob F^7 in slot $C.^6$ The subject and localizer are now in correct position for making the two necessary exposures.

First Exposure

Place patient's head, affected eye downward, on the plate-holder base, with inflated cushion in position, as shown in illustration, being careful that the

inflated cushion does not extend over the marked lines on the cover—otherwise it will cast a shadow on the photographic plate.

If the subject shows a tendency to move about, the horizontal clamp, as shown in Figure 147, must be adjusted to the base of the head and forehead, otherwise the vertical clamp, as shown in illustrations herewith, will be sufficient. The double horizontal clamp can be adjusted for either eye by means of its two off-center holes and clamp screws.

Place the diaphragmed tube in position so that its central rays will exactly parallel the front vertical plane of the patient's eye, as shown in Figure 149.

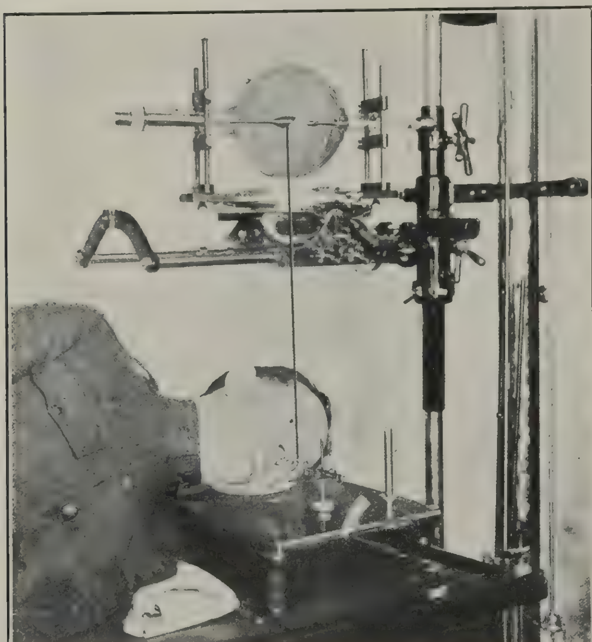

FIG. 149.—Position for first exposure in localization of projectiles in the eye. Be certain that the tube is centered accurately over the cone so that both ball and cone will be superimposed

A plate, having previously been placed in the plate holder, is now placed in the tunnel with the outer flange protruding, as shown in illustration. This will expose one-half of the plate to the action of the rays, while the other half will be protected for the second exposure.

The localizer (fig. 148) is now placed on the stand in front of the affected eye; its trigger is "set" as already described and, after the indicator ball has been adjusted to the plane of the cornea, the entire instrument is pushed forward on its base until the ball presses into the patient's closed eyelid approximately its thickness; the trigger spring is then released and the indicator ball and cone recede exactly 10 mm., thereby permitting the patient to open his eyes and wink them in a natural manner. By referring to localizer chart you will observe that due allowance of 10 mm. has been made by placing the indicator ball and cone just that far from the front plane of the cornea. It should also be borne in mind that the front of the cornea is 10 mm. in front of the shadow of the indicator ball, as shown in your negatives. The tube is now centered over the localizing ball and cone so that the shadows of the two will coincide (fig. 149).

Some object, such as a candle or a piece of white paper, that can readily be seen by the patient, should be placed in alignment with the sights of the indicator, but several feet removed therefrom, and the patient should be instructed to look constantly at this object while the two exposures are being made.

SECOND EXPOSURE

The first exposure having been made with the rays perpendicular to the plane of the plate and parallel to the patient's eye, thereby superimposing the shadows of the indicator ball and cone and their supporting stems, as shown in the right-hand half of illustration (fig. 150) the X-ray tube is then shifted toward the patient's feet four or five inches and tilted so that the indicator rod points to the ball of the localizer, thereby causing the central rays to pass obliquely through the center of the cornea of the patient's affected eye, as shown in Figure 151. The photographic plate must now be shifted by pushing the plate holder inward, by its handle, as far as it will go, thereby protecting that portion that was acted upon by the rays in the first exposure and bring its unexposed half in proper position to receive the rays from the second exposure. In this position the second exposure is made with the rays falling obliquely upon the indicators, thereby separating their shadows, as shown in left half of illustration.

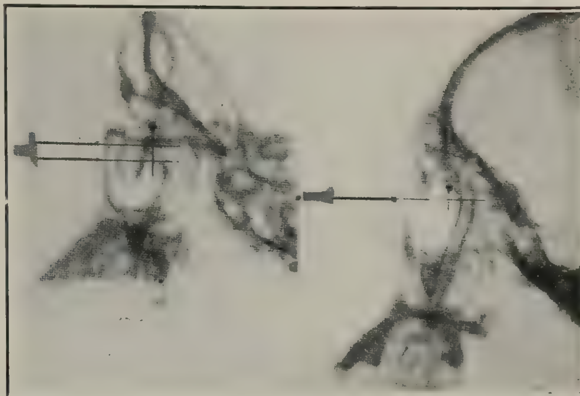

FIG. 150.—Specimen plate of projectile in the eye, illustrating the method of measurement

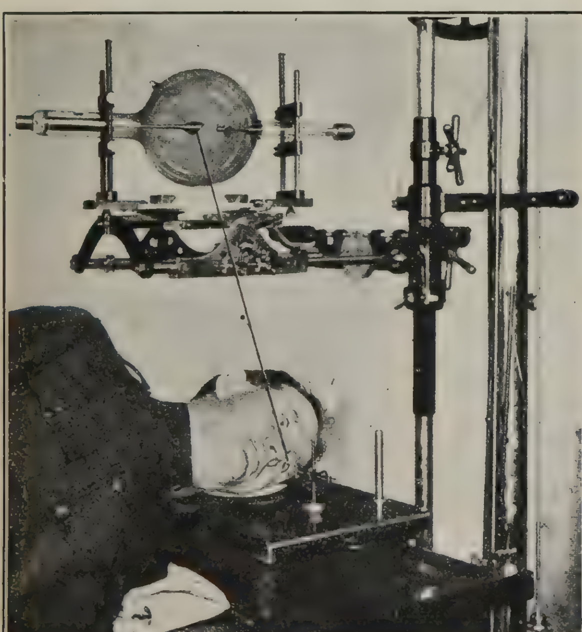

FIG. 151.—Second exposure for localization of projectiles in the eye. Notice shift of tube in order to separate the shadows of ball and cone. Be careful not to produce any lateral shift. The tips of ball and cone must be kept in alignment

It should be remembered that it is not essential that the exposures be made with the tube at any specific distance from the plate, or even that it be the same distance from the two exposures. Neither is it important that the tube be shifted an exact or known distance for the second exposure, as by the use of the charts and Sweet's method the course of the ray is automatically established. This is shown by the line A–D through P^1 and P^2 of outline drawing, Figure 152.

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Charting the Plates

In charting the plates the following method is pursued: Upon the negative (right-hand half of the illustration) which represents the first exposure, a line is drawn through the horizontal axis of the indicator ball and cone which are here superimposed, thereby projecting their supporting stems and establishing the visual axis of the eye (fig. 150).

A second line is drawn at right angles to the first through the center of the foreign body's shadow.

With a small pair of dividers step the distance from the edge of the indicator ball to the intersection of the horizontal and vertical lines that you have just drawn. Then step this distance off on the diagram chart, making a dot with a pen, or a very sharp, hard pencil, to represent the exact distance (distance R. fig. 152).

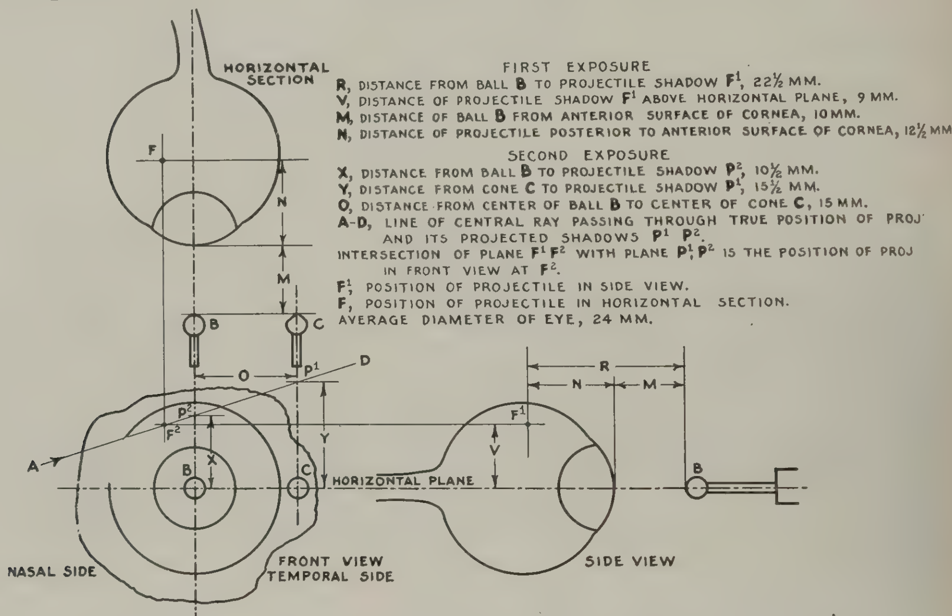

Fig. 152.—Schematic drawing of localizing chart, illustrating the method of obtaining measurements

On the vertical line that has been drawn through the shadow of the foreign body (right-hand half of fig. 150) measure the distance of the foreign body above or below the horizontal line and indicate the same on the chart above or below the axis, distance V locating dot F^1.

Place another dot on the same horizontal plane and draw a line through these two dots, parallel to the axis, projecting into the front view as shown.

Since the position of localizer ball B, as shown on the chart, side view, is the same as when the first plate was made, the location of the foreign body must be at point F^1. We have yet to establish its location to the nasal or temporal side.

Project a line vertically through point F^1 to the 45° angle (see fig. 153), thence horizontally through the horizontal section.

Upon the negative (left-hand of illustration) which represents the second or oblique exposure, a line is drawn through the horizontal axis of both the ball and the cone, thereby projecting their supporting stems and establishing the relation of their horizontal planes to that of the foreign body.

A third line is drawn at right angles to the first two through the center of the foreign-body shadow.

With dividers the distance of the shadow of the foreign body above or below the horizontal plane of the shadow of the ball is measured, and the same is marked by a dot on the front view of the chart just above or below the center B, as indicated by distance X, because that was the relative position of the indicator ball when it cast the shadow. The distance of the shadow of the

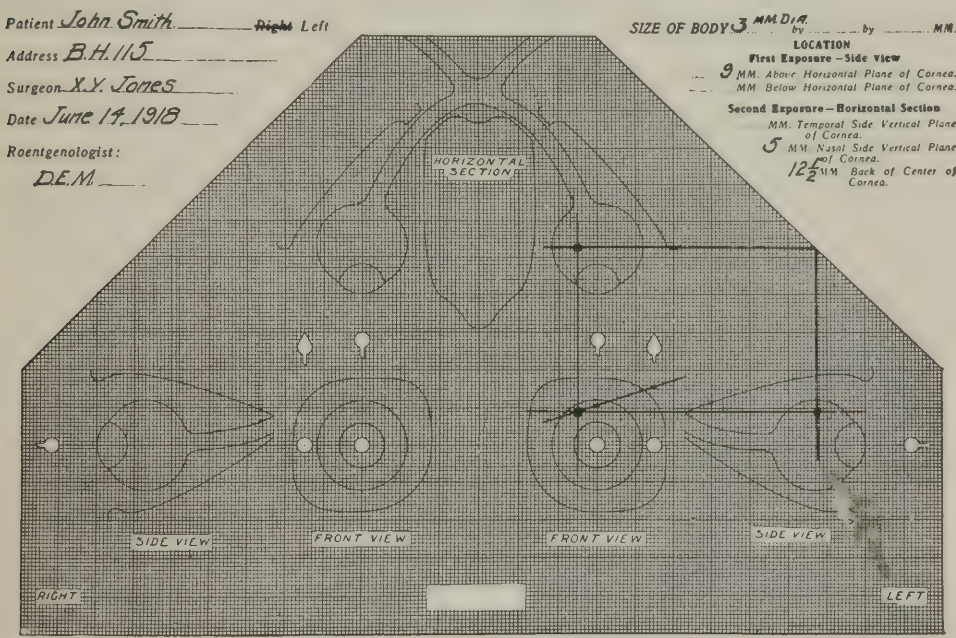

FIG. 153.—Chart used in eye localization

foreign body above or below the horizontal plane of the shadow of the cone is measured, and the same marked on the chart at the point above or below C indicated by distance Y, because that was the relative position of the indicator cone when it cast the shadow.

A line drawn through dots P^1 and P^2 will represent the true course of the rays in the second exposure, and its intersection with the projected line from the side view through the point F^1 will be the position of the foreign body when viewed from the front, while a vertical projection through the horizontal section shows the position of the foreign body to the nasal or temporal side at point F.

In these eye localizations a source of error is the fact that this is a schematic eye, constructed to correspond to the average eye which is about 24 mm. in diameter, but this may vary 3 mm. from the average.

Sometimes the variation can be measured with an opthalmoscope and corrections made, but ordinarily the eye is so injured that this is impossible, and we must assume that the eye corresponds to the schematic eye. This error, of course, would interfere only in cases where the foreign body is located 1 or 2 mm. inside or outside the sclera. In that event one would not be certain whether the foreign body was within or without the globe of the eye.

This point may often be determined in the following manner: Place the patient on his side with the afflicted side next to the plate and center the tube over the eye. Fix the vision of the good eye on a spot in a plane parallel to the plate, so placed that the eye is rotated toward the top of the head. Make an exposure of one-half the correct amount, then shift the vision to a point well toward the feet, still keeping the head fastened securely in place, and expose the remainder of the necessary time.

If there are two images of the foreign body, it is certain that the foreign body moved with the eye and therefore must be in the globe.

It is barely possible for the foreign body to be in an ocular muscle and move, thereby giving two images, but its position near the exterior and anterior portion of the globe would help differentiate this.

In an acute case where a localizing apparatus is not available, this method may be all that is necessary.

EXTRACTION

X-ray guidance during surgical operations is indispensable for the expeditious removal of a certain proportion of foreign bodies. It is applicable not only to the extraction of projectiles and other foreign metallic substances, but also for the removal of pathological foreign bodies, such as renal calculi, encountered in civil life. In fact, if there is any question as to the location of an elusive stone or doubt as to whether or not all stones have been removed, it is possible, by means of the fluoroscopic bonnet and portable X-ray equipment, to make an X-ray examination of a kidney which has been lifted out of the wound at operation. This method of screen control is also useful during the injection of opaque fluids into the urinary tract, during the aspiration of intrathoracic accumulations of fluid, and in the control of injection of air, oxygen, and other gas into the pleural or peritoneal cavity, or into the ventricles of the brain.

The method of intermittent fluoroscopic control is more satisfactory for general use in the extraction of metallic foreign bodies than are electrovibrators, telephone probes, or other similar devices, for the reason that a considerable percentage (approximately one-fifth) of the foreign bodies of war are not magnetizable. Fluoroscopic control methods save time, lessen trauma, and conserve the temper of the surgeon.

The requirements for the malleable band, harpoon, and Hirtz compass methods have already been sufficiently referred to in the preceding section.

Two other methods of fluoroscopic control will be described in detail: The method of the open screen in the darkened room, and the bonnet method in the usual light of the operating room.

FIG. 154.—EXTRACTION OF A FOREIGN BODY UNDER FLUOROSCOPIC CONTROL. THE OPEN SCREEN METHOD IN DARKENED ROOM. THE RED LIGHT ABOVE THE TABLE SERVES TO ILLUMINATE THE SURGICAL FIELD IN THE PRELIMINARY STEPS BEFORE THE DIRECT SEARCH FOR THE FOREIGN BODY BEGINS. BY MEANS OF THE FOOT SWITCH THE RED LIGHT IS TURNED OUT AND CURRENT IS TURNED INTO THE X-RAY TUBE BENEATH THE TABLE, AS ILLUSTRATED IN FIGURE 155

FIG. 155.—THIS ILLUSTRATION REPRESENTS THE RADIOLOGICAL STEP OF THE PROCEDURE OF LOCALIZING FOREIGN BODIES UNDER FLUOROSCOPIC CONTROL. THE ROOM IS IN DARKNESS EXCEPT FOR THE FLUORESCENCE FROM THE SCREEN DURING THE ACTUAL X-RAY LOCALIZATION

OPEN SCREEN IN DARKENED ROOM

The requirements for this method are the usual fluoroscopic horizontal table; a fluoroscopic screen; a proper overhead red or green light, sufficiently bright, preferably under control of the same foot switch that controls the X-ray current; surgical equipment, including sterile sheets, gloves, gowns, and instruments.

No instruments of special design are needed except a pair of narrow-jawed forceps. A special bullet-seizing forceps or a forceps of the type used for exploration of the gall bladder or common duct is usually satisfactory for grasping the foreign body. The forceps of Wullyamoz are bent at a right angle in such fashion that the prehensible portion of the instrument is held in the line of the vertical ray without exposing the hand of the operator.

If it is not convenient to use the ordinary horizontal fluoroscopic table, any wooden or aluminum topped table will suffice if so constructed that an X-ray tube can be placed beneath it without danger of short-circuiting the current. The modern bedside equipment (fig. 156) is very satisfactory for this purpose. The small Coolidge tube at the tube-holding arm can be turned downward and placed under the table at a point vertically beneath the foreign body when the patient lies in the position for operation. Blankets of black or green cloth draped around the table to the floor will prevent the escape of light into the room, or a smaller piece of black cloth can be placed directly around the tube for the few moments necessary for the examination. The ordinary horizontal fluoroscope is, of course, already equipped.

FIG. 156.—Arrangement of the tube and table for the bonnet method

In military hospitals in the forward area there is seldom need for the use of the open screen in the darkened room. When this method is required the patient can be carried into the X-ray room and the surgery done there. This method interrupts, of course, the routine work of the X-ray department and hence for forward hospitals the bonnet method, described below, is preferable, as it can be carried out in the operating room. In stationary hospitals, where there is likely to be more time for deliberate work, the writer considers it desirable to provide a special room for extraction of foreign bodies under X-ray control, employing the method of the open screen in the darkened room for a certain percentage of difficult extraction cases.

One may use the ordinary lead-glass covered, fluoroscopic screen: or an old intensifying screen, no longer useful for radiographic work, may be fastened

to a piece of lead glass by means of adhesive tape and held by an assistant whose hands are properly protected by leaded rubber gloves. Special tables were constructed during the war supplied with a hinged arm for holding the fluoroscopic screen, so that when the screen was not in use it could be tilted back out of the way of the operator.

For the overhead light one may employ an ordinary incandescent bulb, stained red. This red light may be as brilliant as the surgeon desires. The writer prefers a bluish bulb mounted in a yellow globe, which gives a very agreeable light, much like moonlight. On the other hand, the overhead light in daily use in the fluoroscopic room may be utilized in place of a red light for most of the manipulations; if at any stage of the operation more illumination is required, a headlight may be supplied to the surgeon. Where extractions under X-ray control are frequent, it will be advantageous to provide a special source of overhead light, 5 or 6 feet above the fluorscopic table, so arranged with glass filters that a powerful red light is thrown upon the operative field. If this light is equipped with a rheostat for dimming or intensifying the illumination, it will be all the more serviceable. In the absence of more elaborate equipment, a hand lamp equipped with a red bulb will serve.

Before the operation it is important that both the surgeon and the radiologist spend ten or more minutes in an abscurely lighted room, or with the eyes protected by smoked glasses.

After the patient has been made ready upon the table, and the sterile linen has been arranged as for any aseptic operation, an additional sterile sheet, known in France as the velum, is thrown over the operative field and fastened down by towel clips on the side next to the radiologist, opposite the surgeon. On the side next to the surgeon, the sheet is held at its two corners by sterile forceps in the hands of assistants. These assistants may or may not be dressed for sterile work as the circumstances warrant. The assistants holding the front ends of the velum drop it over the operative field, protecting it from the radiologist and his unsterile screen. Figure 154 shows the operating scene at this moment. The red light is then extinguished and the X ray is turned on (fig. 155). The radiologist adjusts the tube under the table so that only a small spot on the screen, not more than 3 cm. square, will be illuminated, and the foreign body is brought to the center of this spot. The tube is then fixed in position and the radiologist makes pressure against the skin with a sterile pointer at a spot directly over the foreign body.

The surgeon notes the point on the skin thus indicated and, if it is a satisfactory path of approach to the projectile, makes his incision there. The radiologist then steps back, the velum is raised, care being taken not to contaminate its underside, and the surgeon proceeds with the incision and dissection toward the foreign body.

During the dissection, at such times as he wants help, the surgeon holds the end of a forceps directly over the point where he believes the foreign body to lie, and the protecting velum, its underside still sterile, is turned down over the wound, the red light is again extinguished, and the radiologist corrects the position of the surgeon's forceps by directing him to move it to the right or the

left, until the correct spot is found. The surgeon has only to work directly downward to come upon the object of his search.

It will be unnecessary in many cases to expose the foreign body completely by dissection; often it is only necessary to determine its approximate anatomical position, especially when it lies in the depth of a muscle. Frequently it will be possible, after making a small skin incision, to extinguish the red light, turn on the X-ray current, and under fluoroscopic guidance insinuate the end of a closed, narrow-jawed, blunt forceps into the tissues until it touches and moves the foreign body. With the X-ray current still on, the jaws of the forceps are separated, the foreign body grasped and extracted. The red light or the ordinary brilliant white light of the room is then turned on, and the remainder of the operation conducted in the usual manner. In some situations it will be possible to turn a jagged projectile so that the extraction forceps will seize it by its sharp or jagged edge or point. A needle may be grasped near one end. One who has not gained experience in this method of extraction can not appreciate the ease with which a foreign body may be secured and removed in this manner. In a series of several hundred extractions performed in this way, the writer has never been longer than 20 minutes, usually much less, from skin puncture to extraction of foreign body, and only twice has he failed to remove the foreign body. Both failures were in cases in which hypodermic needles were broken off deep in tissues too thick to be easily studied with the fluoroscope.

Protection of both the patient and the operator from an over-exposure of X rays is of first importance. It goes without saying that the usual lead lining of the X-ray tube holder protects the patient and the operator from all rays except those illuminating the spot upon the fluoroscopic screen. This field of radiation should be kept as small as possible and nothing but the forceps of the operator should ever enter it while the current is on; sufficiently long forceps should be employed to keep the hands out of the direct rays. Protection of the patient and additional security for the operator is afforded by placing over the tube a filter of at least 2 mm. of aluminum, and by reducing to a minimum the time required for the X-ray observations. Onlookers not directly interested should not prolong the operation by participating in the screen work. The method is entirely safe if reasonable care is taken to minimize the time of X-ray observations. If the eyes have been properly prepared by a preliminary stay in obscurity, 1 or 2 milliamperes of current will suffice. A foot switch is essential. The X-ray current should be off every second the observer's eyes are not intent studying the screen. During early experiences, the X-ray current may be turned on and off twenty or thirty times during the operation; but after the first few cases the extraction will be accomplished during a very few moments.

BONNET METHOD

The bonnet procedure has the advantage over the foregoing method that it can be carried out in the operating room in the usual light by which the surgeon operates.

The requirements are an ordinary fluoroscopic horizontal table, or a makeshift; a fluoroscopic bonnet; and a sighting needle or pointer sufficiently

long to permit the hand holding it to remain outside of the zone of active X rays.

The United States Army bedside unit, which is now being adapted to general practice, affords a very convenient instrument for taking the X-ray apparatus to the operating room, providing the surgeon does not wish to take his patient to the X-ray room. An ordinary massage or nonmetallic table or a stretcher will serve the purpose. The tube-holding arm and tube of the bedside unit is placed under the table, approximately under the foreign body when the patient is in the position for operation. No effort need be made to hide the glow of the X-ray tube, as this type of X-ray operation can be carried on in the most brilliant light needed for operating purposes.

A fluoroscopic bonnet, or, in its absence, a hand fluoroscope of the ordinary type, will be needed. In the latter instance, it will be necessary to provide the radiologist with a pair of smoked spectacles. The bonnet fluoroscope, especially Dessane's, is much simpler and more convenient. As soon as the radiologist finishes his observation, the lower part of the bonnet is turned up and held in this position by springs, while a shutter of smoked glass comes down automatically in front of his eyes (fig. 156). The position of the hood thus lifted eases the weight and materially lessens the inconvenience of its use. The screen in this form of fluoroscope measures 13 by 18 cm., an area much larger than the illuminated field should ever be. For a pointer or sighting device, an ordinary urethral sound or a long forceps may be used, if a special localizing pointer is not provided.

The radiologist must put on the bonnet or a pair of smoked glasses 12 or 15 minutes before he will be needed, unless he is already engaged in fluoroscopic work, so that when called he has only to don the bonnet and step to the operating room.

For anesthesia in these cases, when a local anesthetic is not suitable, nitrous oxide gas is preferable since it is nonexplosive. The danger of an explosion of ether vapor, however, has, in the writer's opinion, been considerably overestimated. He has seen only one case and in this no harm at all was done as the flame was instantly smothered. The danger, of course, is greater with the open drop method than with some form of rebreathing anesthetic device. The Ombrédanne anesthetic mask is very satisfactory for this purpose.

After the patient has been made ready for operation in the position in which the localization was done, the protective sterile velum is placed over him in the manner already described. When the surgeon is ready, the radiologist indicates through the sterile velum, by means of a pointer, the exact spot on the skin which lies vertically above the foreign body. While he holds the pointer in place the velum is lifted on the side next the surgeon, who places the end of a sterile forceps on the skin in the position shown by the radiologist's pointer. The bonnet and velum are lifted out of the way, the surgeon notes carefully the point indicated on the skin and cuts down vertically upon it to find the foreign body. If he does not find it at the depth he supposes to be correct, he ties the bleeding points in order to clear the field of haemostats, and asks to be shown again the spot where the vertical ray corresponding to the projectile passes through the wound. This takes but a moment on the part of

the radiologist and is done as often as required. The surgeon places his sterile pointer in the wound as nearly as possible above the exact center of the image of the foreign body. Correction of the position of the surgeon's forceps is made by telling him to move to the left, right, front, or back, until the correct location has been found. After the extraction procedure has been completed it will be advisable to make still another observation to insure that the whole of the foreign body has been removed.

This method will rarely fail except in badly planned operations where an insurmountable difficulty of an anatomical or physiological nature has been overlooked, or where through some accident it will be necessary to terminate the operation suddenly.

In the case of recent wounds, the surgeon will often prefer to conduct his search through the already existing wound rather than to cut down vertically upon the foreign body. Here again the bonnet will afford valuable control, especially if the tube beneath the table is susceptible of movement.

The bonnet method is particularly helpful in cases of old encapsulated projectiles or foreign bodies. By using a very small diaphragm aperture the radiologist employs the bundle of rays perpendicular to the plane of the table. When the foreign body is brought into the line of this ray and the point marked upon the skin perpendicularly over the ray, the surgeon knows if he dissects vertically downward he can not fail to find the foreign body. Ledoux-Lebard and Ombrédanne have demonstrated the special value of this method in cases of intra-osseous projectiles.

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CHAPTER IX

GAS GANGRENE

Since the comparatively recent discovery and isolation of the germs which cause gas bacillus infection, this lesion, which had been grouped among the more virulent varieties of sphacelus or mortification, has become a recognized and distinct surgical entity. Always of great rarity in times of peace, the wide variation in its clinical manifestations resulted in a correspondingly diverse interpretation of this species of infection. With the advent of the World War, however, it became much more frequent, especially on the Western Front, and afforded abundant opportunity for a thorough investigation. It was then expected that the entire subject would be quickly and satisfactorily standardized and an adequate classification of its more or less complex features formulated. Although considerable progress has been made, the problem has not as yet been satisfactorily solved. Unexpected difficulties have been encountered. Thus, the usual association of several varieties of specific organisms in the same focus of infection, to which, not infrequently, are added one or more varieties of pathogenic organisms, has greatly increased the complexity of the clinical manifestations. Furthermore, it is difficult to account for the fact that infection by a single species of the specific organism may cause widely different results. It is also quite possible that the list of specific organisms that cause this infection is not yet complete and that certain unexplained features of the infection may be due to an imperfect knowledge of its cause. On the whole, while a certain uniformity has been reached in its classification, the general result of laboratory and clinical investigation during the war led to the conclusion that the subject is one of great complexity and that many of its problems have not yet been satisfactorily solved.

ETIOLOGY

Diversity in language and in methods of investigation led to considerable confusion in the classification of the specific organisms which cause gas bacillus infection. Certain varieties which, from their description by observers in widely separated countries, seemed to be different species, were ultimately found to be identical. Other varieties described in pre-war literature were not identified by any observer during the war period. The confusion was still further increased by the frequent association with the specific organisms of some of the more common pathogenic germs, resulting in a considerable modification of the clinical features of the original infection.

Notwithstanding the confusion arising from these various causes, it has been demonstrated beyond doubt that the majority of cases of gas infection are due to one or more varieties of anaerobic bacilli and that the extent and severity of the infection depends directly upon the capacity of these organisms to secrete toxin. Their growth and development is favored by dead muscle tissue and the liquefaction of this tissue by certain proteolytic ferments, which

many of these organisms possess in variable amounts, provides a medium in which, unquestionably, the secretion of the toxin is promoted. A majority of these same organisms possess also saccharolytic ferments which are largely, if not entirely, responsible for more or less gas production, a clinical feature that long since stamped this infection with its classic title. Less important, as well as less constant, is the occasional possession of certain fat-splitting ferments which cause disintegration of the fatty connective tissue in the invaded area.

In close association with these anaerobic organisms, aerobic varieties are almost always found. These play an entirely secondary rôle and are never dangerous when alone. Certain varieties, however, possess proteolytic ferments and by liquefying tissue provide a medium that stimulates the growth and development of the anaerobic varieties. Douglas, Fleming, and Colebrook [1] pointed out that further development of the anaerobes is favored by the capacity of the aerobes to absorb oxygen and thereby to diminish the quantity of this element in the area of infection. Closely associated with the specific organisms of gas gangrene and yet nonpathogenic in character, is a third group of bacilli which produce putrid abscesses in animals and to which the foul odor of the discharge in these infected wounds is due.

While tabulations of these various specific and more or less closely affiliated organisms rarely agree, the writer selected the tabulation published in 1919, by Jablons,[2] in connection with a paper on the subject of gaseous gangrene, omitting, however, a list of aerobic and anaerobic bacteria which, isolated in cases of gaseous gangrene before the war, were not confirmed subsequently by any other observer:

- (1) Toxicogenic organisms, anaerobic:
  - (*a*) Those capable of reproducing the disease in animals—
    - (1) *B. welchii, Gas bacillus, Bacillus aerogenes capsulatus, Bacillus perfringens.*
    - (2) *Vibrion septique, bacillus of malignant edema.*
    - (3) *B. oedematiens, B. gasoedem, B. bellonensis.*
    - (4) *B. fallax.*
    - (5) *B. hystolyticus.*
    - (6) *B. sporogenes.*
    - (7) *B. aerofetidus.*
    - (8) *Streptococcus anaerobicus.*
  - (*b*) Those which do not reproduce the lesions in animals—
    - (9) *B. bifermentans.*
    - (10) *B. putrificus.*
    - (11) *B. tertius.*
    - (12) *Bacillus V of Ghon and Sachs.*
- (2) Aerobes capable of reproducing analagous lesions in animals—
  - (13) *B. mesentericus.*
  - (14) *B. anthracoides.*
- (3) Those which are found in association and produce in animals putrid abscesses or are nonpathogenic are—
  - (15) *B. proteus.*
  - (16) *B. coli.*
  - (17) *B. subtilis.*
  - (18) *B. pyocyaneous.*
  - (19) *B. friedlander.*
  - (20) *B. mycoides.*

Of the various anaerobic organisms, Nos. 1, 2, 3, 4, 6, and 7 possess an active saccharolytic ferment, the *Bacillus hystolyticus* possessing none. No. 1 has a slightly active proteolytic ferment which is more actively present in 5, 6, 7, 9, and 10.

Weinberg and Seguin,[3] in an analysis of 91 cases, found No. 1 present in 77 per cent, No. 2 in 13 per cent, No. 3 in 34 per cent, No. 4 in 16½ per cent, No. 5 in 9 per cent, No. 6 in 27 per cent, No. 7 in 5½ per cent, No. 9 in 2 per cent, No. 10 in 2 per cent, and No. 11 and No. 12 each in 1 per cent. Of the 91 cases, 10 were caused by a single variety of anaerobic bacillus, 14 by several varieties and 67 by both aerobes and anaerobes. There was no instance of an infection caused by an aerobe alone. The frequent association of one or more varieties of these specific organisms, as demonstrated in the above table, is interesting also because of the possibility of consequent inhibition or intensification of the virulence of the infection. Thus the toxins of *B. oedematiens* and of *V. septique* are practically destroyed by *B. sporogenes*. On the other hand, *B. welchii* and *B. oedematiens* mutually stimulate activity. A similar stimulation occurs when *B. welchii* and *V. septique* are associated, while *B. welchii* alone is stimulated by *B. sporogenes*.

Pathogenic organisms frequently coexisting in wounds infected by one or more varieties of gas bacilli include streptococci, diplococci, staphylococci, tetanus bacilli, diptheroid bacilli, and others. Thus Ivens [4] reports 464 cases in 59 of which a virulent streptococcus was isolated and in 15, the bacillus of tetanus. Weinberg and Séguin,[3] in their analysis of 91 cases state that streptococcus was found in 40 per cent, diplococcus in 33 per cent, staphylococcus being slightly less frequent.

Douglas, Fleming and Colebrook [1] discuss certain interesting features of symbiosis, stating that streptococcus, staphylococcus and diptheroids stimulate the growth of *B. welchii* and that with both staphylococcus and streptococcus the stimulation is mutual. Furthermore that streptococcus stimulates the growth of other anaerobic bacilli.

The predisposing and local conditions which favor the development of this infection may be grouped as follows: Predisposing—(1) Systemic, as in the more common types of infection; causes that diminish the powers of resistance, such as fatigue, loss of sleep, lack of nourishment. (2) Loss of blood with consequent loss of antigen bodies, as well as of other elements that ordinarily inhibit infection. (3) Shock, which causes a suspension of nervous activity and regulation. Local conditions—(1) Atmospheric conditions of heat and continued moisture or humidity. (2) The character of the soil. Thus, soil that has been repeatedly fertilized contains large numbers of the specific organisms of gas gangrene. Fragments of clothing and of other material so contaminated and driven into the wound, together with similarly infected shell fragments, frequently cause gas gangrene. (3) Wounds involving the large intestine. Such wounds provide a means of exit for the specific organisms which are indigenous in this part of the intestinal canal. (4) Length of exposure. It is quite obvious that this infection is more common in neglected wounds than in those in which débridement is promptly done.

As to the character of the wound, lacerated and contused wounds caused by irregular high-explosive fragments of low velocity, with a relatively small wound of entrance into which muscle substance may prolapse, create favorable conditions for the development of this infection. The more extensively muscle tissue is damaged the greater the likelihood of infection. Contusion, without laceration of muscle tissue, as, for example, from the pressure of broken bony fragments, predisposes to its death by directly compressing its blood supply. A similar though more destructive condition arises from a cutting off of the main arterial supply or from interference with the venous return. The importance of an intact circulation in preventing the development of this infection is seen in those cases in which the infection appears in wounds of several weeks' duration, subsequent to the ligation of a nutrient artery for aneurysm or for secondary hemorrhage.

Conditions relieved by prompt débridement well illustrate competent predisposing causes for gas gangrene. Thus, irregular pockets from which proper drainage is impossible, hematomas from uncontrolled bleeding, foreign bodies, fragments of clothing, loose bone fragments, damaged and lacerated tissues, all favor, if neglected, the development of this infection. The need of providing free and unrestricted drainage of all discharge from every part of the wound can not be too strongly emphasized.

While gas bacillus infection is unquestionably due to one or more varieties of specific organisms, of which a list has been given, the presence alone of the specific organism in the wound would not necessarily result in infection, for wounds from the discharge of which the specific organism of gas gangrene has unquestionably been cultured have been observed repeatedly to heal by primary or secondary union without the slightest evidence of infection. It is only in wounds in which muscle is so traumatized that it undergoes necrosis and where the damaged tissue is so deeply placed that access of oxygen is difficult or impossible that this justly dreaded infection is likely to develop.

PATHOLOGY

Lesions caused by gas bacillus infection vary according to the virulency of the specific organisms; the presence or absence of associated germs, such as streptococci, staphylococci, the bacillus of tetanus, and the bacilli producing putrid changes; and especially the extent of the death of muscle tissue due to the violence of the trauma or to the destruction of the main or collateral circulation of the part involved. It is therefore impossible to define any single pathological picture that is typical of the infection as a whole.

Reference has been made above to the toxicogenic qualities of anaerobic bacilli and to the proteolytic and saccharolytic ferments which they possess in variable amounts. To their capacity to secrete toxin the greatest importance is attached, for not only do these toxins cause tissue changes leading ultimately to gangrene at the point of infection, but, with their rapid entry into the general circulation, patients quickly succumb to the intensity of the virus. On the other hand, in the absence of toxin secretion, no serious local or constitutional changes are observed.

MULTIPLE HIGH EXPLOSIVE WOUND. MARKED COMMINUTION OF CORTICAL SECTION OF TIBIA SHOWING MIXED AND PURE GAS INFECTION

TOXICOGENIC CHANGES

For anaerobic bacilli to secrete toxins, dead muscle is necessary. Such a suitable medium is usually provided by the force of the trauma, either directly through the impact of a displaced bony fragment or through the crushing of the intima of nutrient vessels, with resulting thrombosis. Where death is due to circulatory interference the color of the muscle becomes purple and on microscopical examination the striæ are intact. On the other hand, when death is directly the result of the action of gas bacilli the color is either brick-red or mahogany, depending upon the degree of hemolysis, and the striation is lost. This change in the color of muscle tissue as well as its loss of contractility and the fact that muscle so invaded remains dry without sign of blood when divided are positive indications of the presence of gas gangrene.

Microscopical examination of the affected muscle shows at first a dilatation of the capillaries and small blood vessels, followed either by a rupture of their walls with small ecchymotic extravasations or, because of the paralysis of the muscular part of the media by the local action of the toxin, multiple aneurysmal dilatations appear. In both, the lumina of the vessels are thrombosed, a condition that still further contributes to the spread of the gangrene.

In necrosis due to ordinary pyogenic infection, nature usually endeavors to restrict the infection by phagocytic concentration and other defensive means. In gas bacillus infection, however, mobilization of nature's protective forces does not take place. On the contrary, extension along the course of the muscle or muscles originally involved is very rapid, and, in the event of the shutting off of the main blood supply, the entire extremity becomes quickly necrotic.

The bacilli are found in the early stages of infection between individual muscle fibers. These become swollen, surrounded with an edematous exudate, and finally, losing their structure, are invaded directly by the infecting organism.

Edema develops early and causes the initial swelling. At first a serous exudate, it soon becomes discolored at the point of infection. Remaining clear at the outskirts of the infection, it extends along the areolar planes and in the subcutaneous tissues, preceding the extension of the infectious process in the muscle planes. Occasionally it spreads with such speed as to deserve the title of "malignant" and under these circumstances it completely outstrips and overshadows the phase of tissue necrosis.

All anaerobic bacilli, with the exception of hystoliticus, though in different degree, possess saccharolytic ferments. Upon this content seems to depend the production of gas. At first deeply seated, it infiltrates individual muscle fibers between which the bacilli have penetrated and, as it increases in amount, extends along the course of the wound to the subcutaneous tissue and so at times over the entire body. Animal experimentation has shown that this gas has no toxic properties. By the pressure it exerts in the deeper planes it probably facilitates the extension of the infection, and by compressing the blood supply increases the degree of necrosis. It can not be too strongly emphasized that it does not usually develop in sufficient amount to be detected in the early stage of the infection and that when it can be recognized the infection has reached a stage in which radical treatment is demanded.

Proteolytic changes include the conversion of necrotic tissue into a mushy shapeless mass of extremely foul odor which, in localized processes, give rise to the formation of putrid abscesses, and in the rapidly extending varieties increase the intensity of the general toxemia. Some of the bacilli of gas infection secrete fat-splitting ferments, with the result that fatty connective tissue is attacked and partially digested.

It is both interesting and important to consider the pathological changes that mark the line of demarcation between healthy tissue and the invaded area. Such a line may be either regular or extremely irregular, due to the unequal involvement of the different planes. In the muscle tissue an area of congestion with small hemorrhages generally is observed, on the proximal side of which muscle fiber still retains its normal contractility, color, and blood supply. If a single muscle only is involved, the infectious process may be limited to that structure extending up and down along its longitudinal axis, for adjacent muscles are well protected by intermuscular aponeurosis acting as a barrier unless there is a shutting off of the main arterial supply, in which event massive gangrene of the entire extremity rapidly develops. The associated serous exudate in the zone of muscle necrosis is usually irritating and infectious, while beyond the line of demarcation it is probably innocuous as long as it remains clear and straw colored and is free from any suspicion of odor.

Lesions found in distant organs are chiefly due to toxemia. The occasional development of metastasis, however, and the recovery of the specific organism from the circulation during life, clearly demonstrate that under certain conditions the infection may become generalized. This is borne out by the observations of Weinberg and Seguin[3] who, in their study of 91 cases, recovered the *Bacillus welchii* in 4 cases before death and in 11 of 13 after death. The *Vibrion septique* was recovered in 3 out of 4 cases and the *B. oedematiens* in two only before death and in 5 afterwards. Further proof of generalization is furnished by the observation of Mullally and McNee[5] in which the bacillus of malignant edema was recovered at the site of three needle punctures four days after the patient was wounded; an amputation of the arm was performed six days subsequent to the receipt of the injury. This patient recovered from the infection only to succumb to an attack of pneumonia one month later. In metastatic gas gangrene the organism is frequently recovered from the secondary focus. These metastases usually occur in the buttock or shoulder, regions ordinarily subjected to pressure in the recumbent posture, with consequent diminution in the local blood supply.

To the region attacked by metastasis the infecting organism travels through either the blood or lymph. While lymphatic transmission is probably the rule, the development of metastasis when the evident path of infection is directly opposed to the course of the lymphatic stream demonstrates the fact that the bacillus must be occasionally transmitted by the blood current. The occurrence of metastasis in an extremity from a primary focus on the trunk may be mentioned in illustration of infection by this route. On the other hand, in the much more frequent metastasis in the buttock or shoulder from a primary focus in the corresponding extremity, the specific organism is probably conveyed through lymphatic channels. While anaerobic bacilli unquestionably

crease rapidly in the occluding thrombi at the point of infection and easily iss into the adjacent blood stream, their further development must be greatly npeded by the oxygen content of the red cell. This probably accounts for ie difficulty in recovering these bacilli from blood smears. To be sure, in the ter stages of the infection when the patient becomes moribund, resistance to ie entrance into the general circulation greatly diminishes and at that stage s well as immediately after death, they are more frequently recovered from ie blood, as Weinberg has demonstrated, than during the active course of the ifection. On the contrary, the absence of oxygen carriers in the lymphatic ream facilitates the transmission of the bacilli by this route, although the mphatic ganglia may more or less effectively retard their progress. The riter knows of no attempt to determine the presence or absence of the specific rganism in the glands which directly drain the primary focus of infection. ivestigation of this part of the subject might lead to very interesting results.

LESIONS IN DISTANT ORGANS

Changes in the abdominal organs vary according to the type of infection. Vhen associated with pyogenic organisms, the liver, spleen, and kidneys show cute degeneration such as is ordinarily seen in septic processes. In gas ganrene alone, these changes are not so marked. In their place these same organs ppear swollen and spongy and on section show a frothy or foamlike infiltration ue to the presence of gas. Although similar changes can be produced in iboratory animal experimentation, it is not at all certain that in man they are ot post-mortem in character. At all events, there is no record of any such bservation during the life of the patient.

Adrenal capsule.—The yellow cortical substance becomes grayish white, ue to the disappearance of the lipoid tissue. The fasciculated cells show egenerative and inflammatory changes similar to those observed in peritonitis ut more rapid in development. In the presence of these advanced changes ı the cortex, the interior or pulpy portion of the glands remains normal. 'hese changes are of interest on account of their possible relation to the changes bserved in the blood pressure of patients suffering from gas bacillus infection.

Brain.—This organ is usually pale and somewhat edematous. The fluid ı both the subarachnoid space and ventricular cavity may be increased. In elayed death, the basal vessels show gaseous infiltration.

Heart.—The muscle fiber is pale and shows cloudy swelling. There may e subendocardial ecchymotic extravasations.

Lungs.—There are often patches of bronchopneumonia, in which occaionally the anaerobic bacillus may be found. There may be small subpleural emorrhages.

Stomach and intestines.—These organs usually are distended, although xceptionally they may be empty.

CLINICAL MANIFESTATIONS

Variations in the type and number of the specific organisms, as well as ieir frequent association with one or more varieties of common pyogenic rganisms, mentioned above in the consideration of the pathology of this

subject, make it necessary to observe a rather wide latitude in any description of the clinical manifestations of gas gangrene. The subject perhaps is preferably approached by a detailed description of individual symptoms followed by their collection into groups according to the severity of the infection.

PERIOD OF INCUBATION

This is usually from one to four days, according to the malignancy of the specific organism and to the extent of the necrosis of muscle tissue. It is noteworthy, however, that this period may be prolonged for weeks or even months. In fact the specific organism may remain quiescent during the entire reparative process and continue harmless for months in the cicatrix, only to be released in the course of an operation then undertaken to remove a piece of shell fragment or other foreign body or to correct a bony deformity resulting from the original trauma, or it may even follow the removal of the cicatrix for plastic purposes. A similar outbreak of the infection occasionally develops in cases of appendicitis in which a secondary abscess may occur months or years after the original operation. In gas infection, however, such tardy activity is not, as in colon infection, necessarily mild but may prove most serious and even may terminate fatally.

INVASION

The invasion is usually insidious. If the infection is not associated with pyogenic organisms, pain, referred to or below the point of infection, is not infrequent. It is rather a more or less sudden intensification of the pain previously existing due to the trauma of the penetrating wound from which it must be carefully distinguished Under similar conditions (absence of pyogenic organisms) swelling is quickly added to the pain, due to the incipient edema of the subcutaneous tissue. This edema gives to the skin above and below the wound a whitened appearance followed by a creamy tint, and makes the surface veins more distinct and dilated. Also it imparts a slightly tense feeling of elasticity, though there is no pitting on pressure, to the subcutaneous tissue. Of the four cardinal symptoms of inflammation these two only are present, redness and heat being conspicuously absent. The frequency with which the streptococcus or staphylococcus is associated with the specific organism, however, accounts for numerous exceptions to this general rule. In that event all four symptoms of inflammation may be elicited.

In addition to the pain and swelling, local symptoms include the appearance of the wound and its immediate environment, the type and character of the edema, the formation, location, and behavior of the gas.

LOCAL SIGNS AND SYMPTOMS

CHARACTER OF THE WOUND

At first, as in a healthy wound, the immediate discharge is serosanguinolent. However, the serous element quickly diminishes in amount, becomes pinkish and discolored, and shortly afterward assumes a dirty brown color. The discharge is irritating to the surrounding parts. The wound rapidly becomes

unhealthy and its sloughy surface is apt to be covered with a gelatinous discharge which, as gas is produced, may contain air bubbles. These same bubbles can frequently be expressed from the wound. The discharge, moreover, usually develops a more or less typically foul odor in the early stages of the infection due to rapidly increasing putrid bacteria in tissues already swarming with the specific organisms. The edges of the wound become necrotic and ragged. With the approach of the gas toward the surface, the skin adjacent to the wound assumes a brown, bronzed, or orange color; in

FIG. 157.—Gas gangrene of arm before operation. (Courtesy of Maj. Benjamin Jablons, M. C.)

the more malignant types the color is blue or violet. In this discolored area, coalescing vesicles appear. These vesicles are numerous in the vicinity of the wound, and occasionally they show a tendency to encircle irregularly the circumference of the extremity. In other cases they seem to follow the course of the superficial veins. If their contents are light in color these vesicles are believed to be due to lymphatic occlusion; if dark in color, to thrombosis of the smaller superficial blood vessels. Later, as the condition progresses, the fluid contents may contain air. The segment of discolored skin containing

these vesicles gradually becomes leatherlike and may eventually be discharged as a slough. Such necrosis is rapid and certain in the more malignant type where the discoloration is blue or violet and is the forerunner of death of the entire extremity below the level of the infection.

EDEMA

This is due to serous exudate both in the involved muscle planes and, afterwards, in the subcutaneous tissue. In the zone of infection it is tinged with blood and swarms with anaerobic germs and, later, with those responsible for the foul odor of the discharge. Receding from the point of primary infection the specific organisms decrease in number until, at the line of demarcation, the serum, although still possessing toxigenic qualities, is entirely free from organisms of any kind. In this area it is considered by some to be relatively harmless, if not actually beneficial. It is thus said to be analogous to the straw-colored exudate in the early stages of infectious peritonitis, which, at

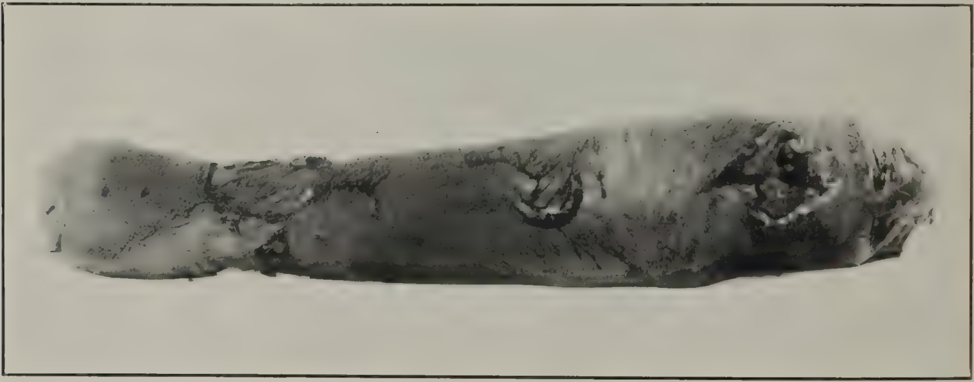

FIG. 158.—Gas gangrene of arm, colored man, after amputation. (Courtesy of Maj. Benjamin Jablons, M. C.)

first free from contaminating organisms, speedily becomes invaded by the spreading infection.

The edema extends more or less rapidly along the lymphatic spaces in the neurovascular sheaths and in the subcutaneous tissue, and while at times it indicates the level of muscle necrosis, it occasionally outstrips this particular phase of the lesion and spreads with frightful rapidity over the entire body and neck. The edema is at times much less compressible than is ordinarily the case, and the line of demarcation is sharply delineated by a distinctly raised wall which permits an accurate estimate of its progress. Such a type of edema seems to be associated with the more malignant forms of gas bacillus infection, especially with those due to the bacillus edematiens.

GAS FORMATION

The presence of gas causes a distinct crepitation which can be detected by gently stroking the overlying skin with a smooth, flat instrument, and, as it becomes more abundant, by pressure with the palmar surface of the fingers. It indicates by its location the muscle or muscles involved and extends in all

HIGH EXPLOSIVE SHELL WOUND; GAS GANGRENE. LEFT KNEE, WITH JOINT RESECTION SHOWING MARKED GASEOUS EMPHYSEMA OF CENTRAL AREAS, AND PUTREFACTIVE INFECTION OF SUPERFICIAL MUSCLES WHICH HAS PRODUCED BRONZING

GUNSHOT WOUND; GAS GANGRENE. RIGHT KNEE, SHOWING DELAYED GAS GANGRENE OF THIGH MUSCLES FOLLOWING FRACTURE AND OSTEOMYELITIS OF FEMUR

directions until the affected muscles are completely necrotic. Intermuscular septa ordinarily check its advance until the entire extremity becomes gangrenous, when gas infiltration is rapidly generalized. It can be detected in the early stages by auscultatory percussion and shortly afterwards by ordinary percussion. X-ray exposures show at first longitudinal streaks which, extending, become gradually more distinct and then quickly develop into air bubbles—an extension which can be readily noted in successive X-ray plates.

As gas production increases, bubbles appear in the discharge or may be expressed from the wound. The length of time elapsing before gas can be recognized is approximately longer when the affected muscle is deeply seated than when it is superficial. When deeply seated, the infection may have gained great headway before this symptom appears. In general, it must be emphasized that the presence of gas is not manifest in the early stages of the infection. The subcutaneous tissue becomes infiltrated with the gas when it passes along the interstices of the wound toward the surface of the body. It is at this stage that it either appears in the discharge or may be expressed from the wound. The possibility of the primary involvement of the subcutaneous tissue has been much discussed. That gas infection develops originally in necrotic muscle is now generally conceded, and where the gas is entirely superficial to the deep fascia, involvement of a small portion of the underlying muscle has been assumed. The strongest argument that has been advanced in favor of the development of this infection without damage to muscle substance rests upon those cases in which gas bacillus infection has followed the subcutaneous injection of some medicinal agent, such as camphor or digitalis, or where it has developed after the infiltration of subcutaneous tissue with saline solution in hypodermoclysis. As a matter of fact, however, it is in patients already suffering from gas gangrene at some distant point that this unusual condition has been noted, and it is quite possible that it may be accounted for as a metastatic manifestation due to the presence of the specific organism in the general circulation.

INCREASING SWELLING

The initial whitening of the skin due to the incipient edema has been noted. With the formation of gas and the continued edema, the swelling increases, involving the extremity more rapidly below the point of infection than nearer the trunk. The gradual extension of the swelling may be demonstrated by successive measurements of corresponding portions of the two extremities, the line of demarcation being at that point where no increase in the circumference of the affected extremity can be detected.

It can not be too strongly emphasized that treatment should not be delayed until the characteristic symptoms of crepitation and odor appear. In the early part of the war radical and thorough débridement of the wound had not been developed, and treatment frequently was delayed until symptoms of infection had appeared, with most unfortunate results. Even in the latter part of the war, because of unavoidable delay in the succor and transportation of the wounded, or because of the virulency of the infection, patients not

infrequently were admitted to hospitals at the front in such a condition that no radical measure could be of benefit. These unfortunate patients afforded abundant opportunity for the observation and study of the later clinical manifestations of the infection.

CONSTITUTIONAL SYMPTOMS

Constitutional symptoms are due to the toxemia as well as to the absorption of chemical products resulting from the destruction and decomposition of the invaded tissues in the infected area.

Circulation.—Acceleration of the pulse is one of the earliest symptoms. In a few hours after the invasion the pulse reaches 130 or higher and is small in quality. At first a temporary rise of pressure is noted, possibly due to suprarenal changes; a rapid fall quickly ensues and, in fatal cases, continues to the end.

Temperature.—The temperature is almost always relatively low, usually not exceeding 101° to 103° F.; it is entirely out of proportion to the quality and rapidity of the pulse. This peculiar combination, namely, a low temperature with an unusually rapid pulse, should immediately excite suspicion of the presence of this serious infection.

Respiration.—Respiration is decidedly increased in frequency due to the rapid decrease in red cells, and other changes that greatly diminish the oxygen content of the blood. In the more malignant cases dyspnea appears, although usually the skin remains pale, without sign of cyanosis, to the end.

Surface of the body.—With the development of the circulatory disturbance and the progressive anemia marked pallor appears. This continues to the end. Jaundice is not infrequent, giving, together with the pallor, a dusky hue to the skin. The surface of the body is usually moist and may be bathed in perspiration.

Bowels.—There is usually constipation; occasionally diarrhea.

Central nervous system.—Patients are usually apathetic and fail to appreciate the seriousness of their condition. Restlessness is not uncommon; delirium rarely appears; consciousness is preserved to the end. Death results from paralysis of the important basal nerve centers.

GROUPED SYMPTOMS

Since gas infection varies widely in virulency, and consequently in the extent and character of both local and constitutional symptoms, it is customary to somewhat arbitrarily assign all cases to one of three groups: (*a*) Those of mild character; (*b*) those of a malignant type; (*c*) those intermediate in severity. It is quite obvious that the line of demarcation between these different groups is not always sharply defined. Thus, an infection which appears at first mild and localized, may suddenly become virulent and spreading, while infections of moderate severity may rapidly develop malignant manifestations. Unfortunately infections, originally serious, rarely if ever become less virulent. In these malignant cases only prompt treatment can save the patient's life.

Mild Cases

In view of the fact that one or more varieties of anaerobic organisms frequently can be cultured from the discharge of wounds which heal without complication, it is not at all surprising that gas gangrene may remain localized. This fortunate result is most likely to ensue when the damage to muscle is superficial, or slight in extent, and the muscle exposed to air; or when the associated anaerobic bacilli are mutually restrictive. Similarly, when a single muscle only is invaded, the infection, although spreading in both directions along its longitudinal axis, may yet be confined by the intermuscular barrier to the muscle originally involved.

In these cases of localized gangrene the infection not infrequently appears after transportation of the patient to a base hospital. The relatively long period of incubation is followed by a mild grade of infection, with the result that the mortality is very much less than in a field or evacuation hospital. In this group of cases the local symptoms differ from those previously enumerated in their extent and frequently resemble the local symptoms of an abscess due to one or more pathogenic gas-producing bacteria. In fact, the symptoms of crepitation common to both types of infection has probably led to erroneous diagnoses. By the inspection of the abscess cavity in the course of treatment the two conditions are readily differentiated. In infection due to pathogenic organisms leucocytic infiltration is extensive, and muscular necrosis, limited to the immediate abscess wall, is manifested by irregularly sloughing strings. The red-brick color, so characteristic of gas gangrene, is absent. The constitutional symptoms in the two conditions present a sharp contrast. In abscess due to pathogenic gas-producing organisms the temperature is relatively high, the pulse bounding and of good tension, the face decidedly red, and, when exceptionally the infection becomes diffuse, delirium with metastatic multiple abscesses may occur, a condition never developing in uncomplicated gas bacillus infection.

Severe or Malignant Cases

In the severe or malignant types of gas gangrene, the intensity of the infection is measured chiefly by the rapidity of extension of the local symptoms and the quickness with which patients become acutely toxic, the latter being indicated especially by extreme circulatory weakness and a condition of collapse. While the evidence of grave constitutional disturbance shows no essential variation, the local symptoms, especially the crepitation, the edema, and the character of the discharge, may vary very considerably. Thus, theoretically, the invasion of dead muscle by anaerobic bacilli alone results in a condition of intense toxemia with little edema and, if the bacilli do not possess the saccharolytic ferment, in little or no gas production. In infection due to *Vibrion septique* edema may be the predominant symptom. As has previously been noted the type and rapidity of extension of the edema may also vary. Thus in infection due to the *Bacillus edematiens* the edema is much less compressible than is the case in infection due to the *Vibrion septique* and, advancing with a sharp line of demarcation in the formation of a raised wall, it may extend much more rapidly over the main part of the entire body. Again the foul odor of the discharge

develops only when one or more putrid bacteria are added to the specific organisms. As a matter of fact, however, such association is rarely, if ever, absent. Considerable variation in the character and arrangement of the bullæ and in the color of the skin near the point of infection is not uncommon, a darker color indicating more extensive vascular changes. Finally the frequent association of the specific organism with pathogenic bacteria may greatly modify the character of the local symptoms. In a general way, gas production, edema, and the development of a foul discharge may be considered fairly constant local symptoms while, according to the nature of the specific bacillus, either gas production or edema may predominate.

CLINICAL PATHOLOGY

LEUCOCYTOSIS

Observers differ materially in regard to the behavior of the white cell in gas gangrene infection. The larger number state that they are diminished. All agree that, in the tissue invaded by the specific organism, the barrier caused by the massing of leucocytes is either defective or absent. This discrepancy in the effect of the infection upon the general and polymorphonuclear count is perhaps to be ascribed to the fact that, in the early stages of infection, as well as in cases of mixed infection in which pathogenic organisms are present, the leucocyte count, although ultimately diminished, may at first be increased. It is also quite possible that the increased leucocytosis, reported by some observers is essentially a relative increase made possible by the rapid and progressive decrease in the number of red cells. More striking is the condition of the red cell itself. There is a marked anemia, even in the early stages, the number of red cells diminishing to perhaps less than one million per cubic centimeter. In an interesting and exhaustive essay on this subject, Jablons [2] has called attention to anisocytosis, stating that the macrocytes predominate at the beginning, while the microcytes predominate toward the end of the infection. He further states that poikilocytosis is constant. In 10 cases there was a noticeable polychromatophilia, nucleated red cells being present in 4 cases. The blood serum in fatal cases shows a definite hemolysis.

Examination of the urine, especially in cases of mixed infection, reveals the presence of albumin and casts.

TREATMENT

PROPHYLAXIS

Débridement of all contaminated wounds, especially of those due to explosive fragments at short range, at the earliest possible moment, is unquestionably the most efficient means of forestalling the development of gas gangrene. Wounds so treated should be left in such condition as to permit free exit of all discharge and should be allowed to heal by granulation, secondary closure being done, if at all, after the danger of infection has passed. This procedure, adopted generally in the latter part of the war, greatly diminished the incidence of gas gangrene and lessened its virulence.

Serum Therapy

As the knowledge of the bacteriology of gas gangrene increased it was generally expected that serum administered both as a prophylactic and also after the infection had appeared, would prove as successful as serum therapy had proved in tetanus and diphtheria. It was found, however, that while some animals could be rendered immune for various lengths of time in the laboratory, the results achieved in man were somewhat disappointing. This was probably due to several factors. In the first place the spread of the infection was frequently so rapid that the patient became either moribund or died before the specific organism could be isolated. In the second place the infection, usually due to more than one variety of the bacillus, was associated with some form of pathogenic organism, such as the streptococcus or staphylococcus, in either of which conditions a serum prepared from a single species would naturally prove of little or no value. This complex nature of the infection led Weinberg and Séguin[6] to replace serum derived from a single organism with one composed of a mixture of the sera of several of the most frequent organisms of gas gangrene. A similar polyvalent serum was introduced by Léclainche and Vallée.[7] The use of this "hit or miss" method was more encouraging. Thus Frances Ivens[4] reported 10 cases treated by the mixture of Weinberg and Séguin with a successful result in 5. The fatal cases were septicemic when the serum was given. M. Weinberg[8] stated that the polyvalent serum of Léclainche and Vallée seemed to have given particularly good results as a prophylactic, especially in wounds in which the specific organism was associated with streptococcus. He further emphasized the fact that the best autovaccine is one prepared from all the organisms both anaerobic and aerobic, found in the wound. Several injections are made daily or every two days and "in certain cases the effect is indisputable." Weinberg and Séguin referred to 6 cases of infection due to *Bacillus oedematiens* which recovered after treatment by anti-oedematiens serum "after the infection had reached an alarming stage." Frances Ivens[9] describes the results of the prophylactic treatment of wounds with anti-gangrenous serum. This writer reports 433 cases, many of which presented clinical signs of gas gangrene and divided them into three groups, as follows: (1) 222 cases (126 fractures) treated by 10 c. c. each of anti-Welch, anti-Vibrion septique and anti-oedematiens serum of Weinberg. (2) 154 cases (110 fractures) treated by 30 c. c. of Léclainche and Vallée polyvalent serum. (3) 57 cases (34 fractures) treated by 30 c. c. Weinberg and 10 c. c. of Léclainche. In each case the serum was given subcutaneously in one pint of saline at the time of operation.

RESULTS

Group (1): Mortality, (*a*) where the serum was given at or before the first operation, no case died of gas gangrene; (*b*) amputation, of 14, 2 died after a fortnight from streptococcal septicemia; (*c*) conservative treatment, serum therapy has permitted "conservative treatment instead of amputation in a large number of cases." The result in 10 cases was not ascertained owing to early evacuation of the patients. Group (2): (*a*) Mortality, 19 fatal cases, of which 3 were due to gas gangrene and 3 to gas gangrene with concurrent septicemia; (*b*) amputation, 4 of 15 were fatal, 2 with concurrent septicemia.

In the majority of cases no severe streptococcal infection occurred during the period of preventive administration with the Léclainche polyvalent serum. Group (3): (*a*) Mortality, 2 cases, one of massive gangrene; (*b*) amputation, 3 cases, 1 for streptococcal infection, 2 for secondary hemorrhage. Gangrene was present at the beginning of treatment in 10 cases. Of these, massive gangrene developed only in 1, 15 days after the preventive dose of serum had been given. Frances Ivens[9] concludes that a powerful antigangrenous serum is of real value in preventing gas gangrene; used in sufficient quantities it is of great value as a disintoxicating agent in cases of advanced infection; that the Léclainche and Vallée polyvalent serum has a marked effect in cases with concurrent streptococcic infection; that anaphylactic phenomena were frequently averted through the dilution of the serum with normal saline solution. Before secondary operation, a further fractional dose of the serums should be administered.

While these interesting results seem to indicate that serum administration is a valuable method of treatment, it is perhaps unfortunate that no attempt was made to compare them with those of a fourth group in which surgical measures only were employed. Unquestionably the virulence of gas gangrene, irrespective of the special etiological organism, varied according to the location of the battle line, the question of easy or difficult succor and transportation, the presence of heat or moisture, and other well-known conditions. While the 433 cases reported by Ivens occurred between March 21 and September 6, 1918, in patients "recently wounded, arriving at the hospital for primary operation," it is quite possible that conditions favored a relatively mild grade of infection. It is believed, without belittling in any way the results obtained in these 433 cases, that in other parts of the battle line the mortality might have proved much greater in an equal number of cases treated by similar methods. At least during the Meuse-Argonne operation, patients were admitted for primary treatment to an evacuation hospital not infrequently with the infection so far advanced that no form of serum therapy could possibly have been of any avail. In this connection it is interesting to compare the results obtained by serum therapy within the German lines with those of Frances Ivens.[9] Herman Coenen[10] reported 1,180 wounded injected immediately with polyvalent serum. Of these only 8, of whom 4 died, developed gas gangrene. Of 75 wounded not injected, 8, of whom also 4 died, developed gas gangrene, a very much higher percentage. The serum was given in doses of from 20 to 40 c. c. and later in larger doses intraveneously. Anaphylactic complications were rare and were manifested by dyspnea, heart weakness, and coma, resulting rarely in death. In 1917, Aschoff[11] reported 2,356 wounded, of whom 223 were injected with polyvalent serum, of whom 98 died (43 per cent), while of those not injected 68 per cent died.

SURGICAL TREATMENT

Gas gangrene, irrespective of the efficiency of prophylactic serum therapy, demands prompt surgical attention. The shorter the period of incubation, the more prompt should be the treatment. Especially where the infection shows a malignant tendency the greatest precaution should be exercised to detect it in

its incipiency. Treatment consists either in the excision of the infected area, together with all dead tissue, or of amputation. On the trunk and buttocks, obviously excision only is available. In the extremities the question of amputation must receive due consideration. Excision is justified where the period of incubation has been relatively long, where the infection is near the tip of an extremity, where the infection is localized or very slowly spreading, where the main circulatory channels are intact, where no fracture exists, where no large joint has been opened, and, irrespective of its virulence, where the infection involves the trunk. On the other hand, amputation is indicated in extensive laceration of the soft parts, where several groups of muscles are invaded by the infection, where there is an extensive comminuted fracture with or without opening into a large joint, where gangrene is self-evident, where the main vascular channels are divided, and where the symptoms of general toxemia develop early. To advise delay in the presence of one or more of these conditions until the question of the rapidity of extension can be determined, is to waste valuable time and to jeopardize the chances of recovery. A third group comprises infection on the border line. While prompt operation is as essential in these as in the more serious types of infection, the question of excision or of amputation depends upon the individual judgment of the surgeon. Many lives have undoubtedly been sacrificed by conservatism which might have been saved at the expense of the loss of a limb. In cases of doubt, amputation is the operation of choice.

In either excision or amputation, the narcosis, for obvious reasons, should be as short as possible, and all constriction during and after the operation, should be avoided, for the pressure so exerted still further decreases a local blood supply already severely impaired, and mechanically forces poisonous infectious products through lymphatic and vascular channels into the general circulation. The object of excision should be to remove foreign bodies, including shell fragments, clothing, and all dead tissue, especially necrotic muscle, stopping only when the divided muscle tissue both bleeds and contracts; to remove all hematoma; to check all bleeding; and to leave the operative field free from pockets so that all discharge shall pass without possibility of retention into the enveloping dressing. Large joints, if involved, may require excision, although in these cases, amputation, as already stated, is usually preferable. All fractures should be so treated as to avoid constriction by any form of retentive apparatus.

When amputation is indicated, no delay is justifiable. He who hesitates will frequently lose his patient. Only the plane, not the time, of amputation is to be determined. It should be at a level sufficiently high to permit of the division of healthy contractile muscle and, if possible, on the proximal side of the area of edema. As in the case of excision, no closure of the operative wound should be attempted. Circular or lateral flaps of skin and subcutaneous tissue are advocated. These may be easily and quickly fashioned and eventually brought over the end of the stump when all danger of infection has passed. In this way secondary amputation, involving further sacrifice in the length of the extremity, may frequently be avoided. Such a procedure is far preferable to the alternative measure, the so-called guillotine amputation, in which the

skin, muscle, and bone are all divided at the same level. The dressing after either excision or amputation should be loosely applied and arranged so as to avoid pressure or constriction. Antiseptic wet dressings have been advocated to prevent the reappearance of the infection in the wound, such as Dakin's solution, hypertonic salt solution, peroxide of hydrogen, and weak solutions of sulphate of quinine. Some prefer to leave the wound freely exposed to the air. This, at least, has the advantage of facilitating dressings without the excessive pain of which patients almost invariably suffer when the compresses, partially dry and closely adherent to denuded tissues, are removed. Of all local applications, dichloramine-T is preferred, as it combines a certain antiseptic value with the possibility of removal of compresses previously moistened by it, with the minimum discomfort to the patient. The "open air" method also is of value, especially if combined with some form of cage protection arranged so as to avoid pressure or constriction of the stump.

While metastasis in pyogenic infection is usually the precursor of a fatal termination, it must not be so regarded in gas gangrene. This rare complication, occurring usually in parts subjected to pressure, such as the buttocks or shoulders, must be attacked in the same way as the original focus of infection, namely, through the excision of the necrotic tissue, the wound being left open. A considerable number of recoveries after operation for metastasis have been reported, probably to be explained by the difficulty the specific organism encounters in its effort to flourish in the general circulation.

While radical surgical treatment is invariably indicated in all cases of gas gangrene in which the patient is not moribund, the mention of other measures less frequently practised, should not be omitted. Chief of these is treatment designed to increase the blood supply in the infected area. This may be accomplished either by cataplasm or by enveloping the limb with continued hot applications, always taking care to avoid constriction. By increasing the blood supply and therefore the oxygen content, the activity of anaerobic organisms is correspondingly curtailed. The Bier method of constriction, well on the proximal side of the infection, has also had a limited trial, chiefly by its author and a few others in German hospitals, with a certain amount of success. In still other cases, through special apparatus, devised in German hospitals, intermittent or rhythmic constriction is applied to the affected extremity with more satisfactory results than when the constriction is stationary. The writer has failed to find any mention of the application of constriction to the treatment of gas gangrene by any member of the Allies. For this reason the actual value of this method is more difficult to estimate than the value of other methods of treatment which were in general use by friend and foe alike.

Theoretically the insufflation or injection of oyxgen into the infected field ought to inhibit, if not actually paralyze, anaerobic activity. Because of the impossibility, however, of oxygen so injected coming into direct contact with all specific organisms, this method proved of little value. Furthermore patients so treated are exposed to the danger of the entrance of gas directly into venous channels with, at times, a fatal result.

During the war, transfusion was occasionally given and while its value was not generally admitted, favorable reports were cited in a limited number of cases.

PROGNOSIS

The prognosis of gas gangrene depends upon the nature of the specific organisms, their association with pyogenic organisms, and the stimulating or inhibitive effect of each upon the others' activities. Local conditions and the type of a warfare also influence the prognosis. In the discussion of the pathology and symptoms of gas gangrene, these factors received due consideration. The question of the location of the infection, irrespective of its type, modifies the prognosis. Cases in which the trunk or buttocks are primarily involved, having a mortality of about 50 per cent, are more serious than infections of the extremities in which the prognosis becomes more favorable as the tip of the extremity is approached.

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CHAPTER X

TETANUS

The incidence of tetanus in the American Expeditionary Forces was decidedly low; so low, indeed, as to warrant the statement that, as a disease, we had no real clinical experience with it: only 36 cases were reported as being associated with 176,132 battle injuries, or a rate of 0.014 per thousand.[1] This fact in itself is worthy of more than passing notice and is but a further exemplification of our good fortune in being able to profit by the experiences of our Allies.

The relationship of soiled gunshot wounds and the occurrence of tetanus was well understood prior to the beginning of the war in 1914, and such injuries occurring on the highly fertilized ground of the battle fields of France were inevitably followed by a high incidence of tetanus. However, the Allies did not anticipate any such number of cases of tetanus as occurred in the first few months following the beginning of the war. Even had it been otherwise, there was neither organization nor adequate material for proper administration of antitoxin. Within a very few months, however, the British ordered that a preventive dose of antitetanic serum be given to every wounded man.[2] The results of this order were reported to be excellent; in the latter half of the year 1915 only 36 cases of tetanus developed among those who received a preventive dose of antitetanic serum within 24 hours of receipt of injury.[2] This measurable, though not entirely complete, control is graphically shown in Chart VI, which is a compilation of Maj. Gen. Sir David Bruce, chairman of the British war committee for the study of tetanus, to show the ratio per thousand among the cases of tetanus.[3]

The case incidence shown in Chart VI refers to cases of tetanus arising in hospitals in England among the wounded arriving there from the battle fields, and it does not have to do with the cases occurring in France; however, another study by Cummins[4] which combined the incidence figures for the British Expeditionary Forces and those used by Bruce, shows a very similar curve.

The elevations in the incidence curve as shown in Chart VI may be explained as being partly due to periodic, increased battle activities, and partly to the occurrence of trench foot. More especially is this true, in so far as trench foot is concerned, in 1916, to which further reference is made below. What is of greater interest, as regards the American Expeditionary Forces, is the almost uniform flattening of the curve during 1918, at a time when we were actively engaged with the enemy.

VARIETIES OF TETANUS BACILLUS

Tulloch,[5] by means of serological tests, identified four classes of tetanus bacilli. Twenty-three strains of the tetanus bacillus were obtained from war wounds of men not suffering from tetanus. Seventeen of these strains belonged

to Type I, 3 to Type II, 2 to Type III, and 1 to Type IV. This relationship of type incidence did not obtain, however, in organisms from cases of tetanus: whereas 74 per cent of the tetanus bacilli obtained from nontetanus cases belonged to Type I, only 41 per cent of tetanus among the wounded could be attributed to Type I.[3]

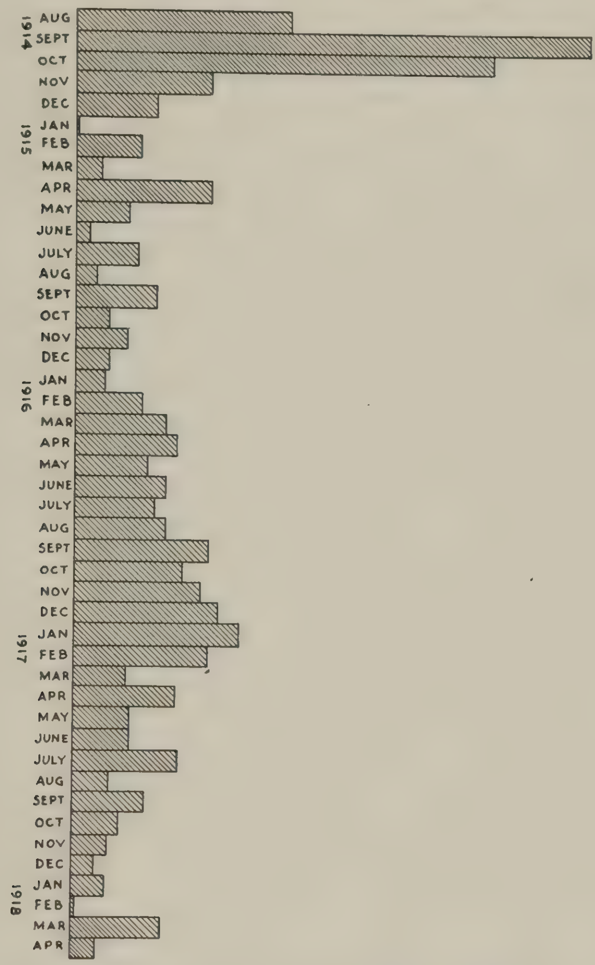

CHART VI.—Incidence of cases of tetanus. Ratio of cases per thousand wounded, by months

PREVENTION

SERUM PROPHYLAXIS

Once the necessity for the administration of antitetanic serum to all injured men was fully appreciated, the belligerent nations so organized their medical forces as to insure the administration of the serum at the earliest possible moment following the injury. This meant the serum must be as readily available, and practically as far forward, as was the first-aid packet; some means of rapidly determining, by a mark—usually an iodine-painted cross on the fore-

hand—or by ticketing, whether or not an acutely injured man had received an adequate dose of the serum; and finally a checking up at the operating hospitals to insure protection in cases in which, through inadvertence, the administration of the serum had been omitted.

The British adopted 500 units as the preventive dose, to be given subcutaneously at a distance from the wound; the French, 10 c. c. (equivalent to about 600 units).[2]

It was expected that this routine injection of serum would bring about the lowest possible incidence rate of tetanus; however, when, with the occurrence of large numbers of trench foot, it was observed that with such a condition tetanus frequently was associated, it was realized that the portal of entry into the body by the tetanus bacillus need not necessarily be an open wound.[6] Therefore all cases of trench foot were included with battle injuries for which the serum was to be administered as a matter of routine, with the result that in trench foot the occurrence of tetanus was prevented.

It was appreciated by the British that 500 units of antitoxin was in many instances too small a dose, and on July 4, 1917, modified instructions required the use of 1,000 to 1,500 units "in all deep wounds in those which are contaminated with dirt, and in those in which there is fracture of bone."[3] The size of the dose, however, was not fully determined as late as December, 1918. Bruce at that time announced his preference for multiple and smaller doses,[3] an attitude that was based upon the fact that the antitoxin disappears within the body within a relatively few days.

Duration of Passive Immunity

With the view of determining the duration of immunity conferred by antitetanic serum, MacConkey and Homer[7] carried out a series of experiments on guinea pigs. In these experiments it was found that immunity from the minimum dose was considerably diminished at the end of 10 days, and at the end of 2 weeks it had about disappeared; immunity could not materially be prolonged without increasing the dosage of serum to a degree impractical in man. They concluded, therefore, that it is necessary, in order to maintain immunity, to repeat the usual protective doses about once a week during the danger period.

As stated above, the British, in 1917, required an increase of the initial dose in certain classes of wounds, from 500 units to 1,000–1,500 units. The British tetanus committee, in the same year, recommended that, additional thereto four doses, each of 500 units, should be given at intervals of seven days. This latter recommendation was responded to variously, from 40 to 90 per cent;[3] consequently, it is impossible to say definitely what influence multiple doses of serum had upon the lowering of the incidence of tetanus. During the fall of 1918 the strength of the primary dose to be given at the front was increased to 1,500 units, with the hope that a higher degree of immunity might be obtained. Second, third, and fourth doses were to be given at weekly intervals, the strength of each to be 500 units.[3] Since the war ended soon after this last change in the administration of the serum inadequate time remained to determine whether or not any improvement resulted from it. What is of particular interest, however, is the fact that, with the increase of the number of multiple injections, the

mortality rate progressively decreases in those contracting tetanus. There is a relationship between prophylactic injections of antitetanic serum and the prolongation of the incubation period of tetanus, which must be taken into consideration in the present connection, for it is possible the decreased mortality mentioned above might to a certain extent be attributable to cases with lengthened incubation periods; a long incubation period goes hand in hand with low mortality. According to Bruce,[3] the average incubation in days in 1914–15 was 13.4; 1915–16, 31.2; 1917–18, 46.19.

SURGICAL PROCEDURES

The tetanus bacillus being an anaerobe, thriving best on putrescent tissue, it follows that the early and absolute excision of such tissue, as well as foreign bodies, ranks first as a prophylactic. This was one of the great surgical lessons which the war taught and was not appreciated thoroughly until 1917, and after other and much less satisfactory methods had been tried out. It is true that tetanus was only one of the several kinds of wound infection for which wound excision was devised, nevertheless the agreement is general that thorough wound excision had a material influence on the incidence of tetanus following its general adoption in the spring of 1917. On the other hand, nothing occurred during the war to change the opinion obtaining prior thereto that operation should be avoided in cases of tetanus, for by the time tetanus symptoms appear there is already a general toxic condition.

Because it was recognized so frequently during the war that tetanus bacilli could lie dormant for surprisingly long periods, only to light up on surgical interference, the administration of a prophylactic dose of antitetanic serum was generally practiced prior to secondary operation on war wounds and upon manipulations incident to the reduction of compound fractures.

MODIFIED TETANUS

With the widespread use of antitetanic serum for the prophylaxis of tetanus, classical forms of the disease occurred less commonly than the modified (local tetanus). Burrows [8] states that this localized tetanus may be splanchnic, cephalic, or seated in the limbs, and explains its occurrence on the basis of laboratory experiments with animals. These experiments showed that the tetanus toxin gains access to the nervous system either by the general blood stream or by the motor nerves. The injection of antitoxin in cutting off approach by the blood stream permits the toxin to find access only along the motor nerves. Hence it can cause only local spasticity.

MEMORANDUM ON TETANUS, AMERICAN EXPEDITIONARY FORCES

Based upon the facts outlined above, the following information was promulgated to the medical officers of the American Expeditionary Forces for their guidance in the prevention and treatment of tetanus:[9]

Spores of the tetanus bacillus are universally distributed in soil that has been cultivated and manured. In consequence they are virtually constant throughout the battle fields of France. And since the soil inevitably gets upon the clothes and bodies of soldiers, all wounds must a priori be regarded as probably contaminated with tetanus. Tetanus spores

in such wounds may at any time develop into tetanus bacilli and produce tetanus toxin, with consequent development of symptoms of the disease.

The tetanus bacillus thrives particularly on injured tissue. Wounds with tissue destruction, especially if there are pyogenic infection and blood clots, are particularly dangerous. Wounds may appear clean and heal by primary intention and nevertheless harbor tetanus bacilli; or tetanus spores may remain latent in such wounds, and when secondary operation produces tissue death or small blood clots they may develop and cause tetanus.

Tetanus antitoxin.—Tetanus antitoxin neutralizes, multiple for multiple, the toxin of the tetanus bacillus. However, it must be remembered that the toxin produced by the bacillus becomes very rapidly attached to the nerve cells which it injures, and toxin which has become fixed in this manner is amenable to the neutralizing action of the antitoxin to a very slight extent only or not at all.

For this reason, the prophylactic value of tetanus antitoxin has been established beyond doubt, but the success of its therapeutic use depends largely upon an early diagnosis and proper administration.

Prophylactic use of tetanus antitoxin.—A prohylactic of 1,000 units of tetanus antitoxin will be given to all wounded, whatever the nature or severity of the wound. This should be done as soon as possible after infliction of the wound, preferably at the battalion aid station. Some of the antitoxin will be furnished in syringes, but it is impossible to provide all of it in this form. Care will be taken, therefore, that battalion aid stations and other advanced dressing stations be provided with a supply of sterilizable 10 c. c. syringes and suitable needles for serum provided in bottles.

Since tetanus antitoxin is eliminated by the body within 10 to 14 days and since the incubation time of the disease varies greatly, depending upon fortuitous circumstances, such as the extent of tissue death and secondary infection, at least one subsequent dose of 1,000 units will be given after an interval of 7 days. It is recommended that officers giving these repeated doses take cognizance of the memorandum on anaphylaxis and be guided in their serum administration thereby.

Tetanus antitoxin will also be administered as a routine measure in the following conditions: 1. Upon the recognition of "trench foot" with or without skin abrasion. 2. In case of frost bite. 3. During operations performed under conditions of unsatisfactory asepsis, e. g., emergency operations, operations for hemorrhoids, fistulæ, or any conditions where fecal contamination is a possibility. 4. During secondary operations necessary in the course of treatment of wounds received 7 or more days previously. 5. Following the manipulations incident to the reduction of compound fractures or dislocations, after the removal of adherent drains or any other procedure resulting in disturbance of the healing process in a wound 7 or more days old.

The antitoxin will be administered subcutaneously, preferably over the lower abdomen by or under the immediate supervision of a medical officer.

All injections, with amounts and dates, signed by the officer administering them, will be entered on patient's field medical card.

In addition to the above regulations for the routine administration of tetanus antitoxin, medical officers are advised that two injections may not be sufficient in all cases. In severe injuries where prolonged suppurative processes persist, especially when fecal contamination of the wound per rectum or through intestinal fistulæ is present, and when much tissue necrosis occurs, three or even four doses may be indicated. The attending medical officer must bear this in mind and exercise judgment accordingly in the individual case.

Early diagnosis.—As stated above, the success of specific treatment in tetanus depends primarily upon early diagnosis. For this reason surgeons should be constantly on the alert for local manifestations which often precede the development of generalized tetanus. Since the toxin is conveyed to the central nervous system by way of the nerve trunks, there may be early rigidity, spasticity, or even twitching of the muscles surrounding the wound—which occasionally may be accompanied by pain and a local increase of reflexes. These symptoms, as well as "sore throat," "stiff neck," early trismus, and in head wounds, facial paralysis, should be constantly watched for and nurses should be instructed to keep this in mind whenever dressing a wound or doing other services for patient.

By conscientious attention to early manifestations of this nature life may be saved. Immediate treatment should be instituted in all doubtful cases.

Treatment with antitoxin.—When the early symptoms of tetanus have been recognized or when the disease has distinctly manifested itself, energetic treatment with antitoxin should immediately be instituted. There are many different ways of administering the antitoxin, and it is by no means plain as yet whether the subcutaneous, intravenous, or intrathecal method will eventually prove to be the most efficacious. However, it would seem that in cases recognized early a combination of immediate intrathecal and intramuscular injections is advisable.

In every case strongly suspected of being tetanus at least 5,000 units of tetanus antitoxin should be given intrathecally as soon as possible. This is done by lumbar puncture, preferably under an anesthetic. The serum should be injected slowly and in volume should about replace the amount of spinal fluid withdrawn. When little or no spinal fluid flows, as occasionally happens, a relatively small volume of serum should be injected (about 5 c. c.), and this very slowly. In all cases intrathecal injections should be done slowly, either by gravity or directly with a syringe, and repeated within 12 hours if the first volume injected does not contain 5,000 units. After such injections it is a good plan to raise the foot of the bed and remove the pillows. At the same time 8,000 to 16,000 units of antitoxin should be administered intramuscularly, with observance of all precautions spoken of in the circular dealing with dangers of anaphylaxis. The intrathecal injection will often give rise to meningeal irritation and turbid spinal fluid, which, however, need cause no alarm.

Both the intrathecal and intramuscular injections may be repeated daily for two or three days. It is rarely necessary to inject subsequent to this, because any effect the antitoxin will produce results from the first injection, since antitoxin is not completely absorbed for several days and is not eliminated completely for 10 or 12 days.

Supplementary treatment.—Morphine and other sedatives should be given with the idea of resting the patient, and they should be administered in doses sufficient to give the most adequate physiological effect compatible with safety.

As soon as the diagnosis of tetanus is made the case will be reported by telegram to the chief surgeon, A. E. F.

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CHAPTER XI

TRENCH FOOT

ETIOLOGY

Trench foot is the name given to the combination of vasomotor, nervous, and trophic conditions arising in the feet of soldiers immobilized in the trenches during the war 1914–18. Since the American Expeditionary Forces had relatively little experience in trench warfare, it obviously follows there could be no great number of such foot conditions in these forces attributable to the peculiar conditions of trench warfare; however, 2,064 admissions to hospital were due to trench foot in our Army.[1] The major portion of these admissions arose from conditions other than those connected with trench warfare, and in all probability would have been called by another name, such as chilblain or frostbite, were it not for our knowledge of the subject acquired from the French and the British. As a matter of fact, the British spoke of it as frostbite during the earlier years of the war,[2] as did the French,[3] the change in name being due to the fact that, though frostbite may have been justified as a name by the appearance of the affected parts, it was not so by the climatic conditions, for trench foot occurred more especially during damp weather when the thermometer did not reach as low as the freezing point.

The causative agencies are almost invariable.[4] They are cold, prolonged immersion in water or mud, accompanied by motionlessness, all of which thus tend to affect the circulation in the lower extremities. Such agencies obtained to a greater extent during the earlier years of trench warfare when many of the trenches were of relatively poor construction, without dugouts, and in many places illy drained. And because of the exigencies of service, relief from trench duty was deterred for a longer time than later. For protection against enemy fire, men hugged the bottoms of the trenches, knee deep in water or mud, unable to change their footwear for days at a time. Little or no early attention was paid to the constricting influence of wearing apparel on the legs and feet—a very large contributing factor in the production of trench foot.

PATHOLOGY

The essential pathological feature of trench foot is an ischemia due to damp cold, with or without a contributory external constriction.[4] This interruption in the circulation through the capillaries alters the capillary walls, thus leading to greater permeability and causing edema and stagnation,[5] either or both of which set up the evolutional stages referred to below under symptoms.

Raymond and Parisot,[3] searching for an infectious agent in cases of trench foot, found both the blood and cerobrospinal fluid negative. In studying the lesions, however, they reached the conclusion that certain fungi, which they

isolated from smears of the liquid of blisters on trench feet, became parasitic and pathogenic under the influence of more or less continuous immersion in cold water, and readily invaded the body through the macerated epidermis. These findings have not been confirmed by other investigators among whom there was a unanimity of opinion that trench foot is not an infectious disease.

SYMPTOMS

Because of the evolutional changes observable in trench foot, unless checked either by removal of cause or by treatment, the clinical picture of the condition as a whole may readily be divided into stages.

First stage.—Primarily the man affected begins to feel a painful cold and numbing sensation, followed by a prickling and burning sensation extending to the legs, frequently of sufficient intensity as to interfere with walking.[4] Usually the pain is severe enough to require morphine. It is a painful anesthesia and one feels as though one is walking on cotton.[3]

Second stage.—In addition to the painful anesthesia there is now edema. Usually the skin is red; it may be blanched. The blush and its accompanying swelling may extend from the foot to the middle of the thigh.

Third stage.—In this stage bleb formation is superimposed on the swelling. The discoloration—sometimes mottled due to hemorrhage—and painful anesthesia remain. The blebs are irregular in shape and vary in size; they may contain serum or blood, and their floors are of a gelatinous material.

Fourth stage.—Infrequently a case is so severe as to result in more or less deep mortification of the tissues of the foot, with or without a preceding blister formation. When the blebs are present their gelatinous floors become dark, dry, and of a boardy consistency.

PROPHYLAXIS

The occurrence of trench foot among the American Expeditionary Forces was regarded as an indication of a lack of good sanitary discipline,[6] because experience had shown that the prevalence of this disease could be precluded by providing proper facilities to units for the care and treatment of the feet and by a strict daily routine within organizations. Organization commanders were made directly responsible for the provision and availability of suitable facilities, and further, for seeing that the men of their commands made full use of them.

The following instructions, published in general orders, General Headquarters, A. E. F.,[6] comprise all the essential features of foot hygiene to be observed in the prevention of trench foot:

* * * * * * *

3. The chief predisposing and exciting causes of "trench foot" are as follows: 1. Hygienic: (*a*) The existence of systematic disease. (*b*) Insufficient nourishment, particularly hot foods, and lack of sleep and comfort. (*c*) Too infrequent changes of shoes and socks, allowing of accumulation of bacteria-laden secretions, with a consequent maceration of the skin of the feet. 2. Circulatory interference: (*a*) As the result of the wearing of tight shoes, socks, leggings, puttees, or breeches. (*b*) As the result of long continued standing or sitting without exercise and with the feet and legs in constrained positions. (*c*) As the result of prolonged exposures of the feet to the effects of wet and cold.

4. The commanding officers of all units will be held personally responsible that the following instructions are carried out under the personal supervision of a commissioned officer: (*a*) That there is available a sufficient supply of dry, clean, well-fitting, woolen socks. All men will be instructed to habitually wear socks without garters. The tendency of the sock to creep down is prevented by fastening to the breeches by means of safety pins. (*b*) That there is available for each man present not less than one change of shoes or boots, and that all boots and shoes are in serviceable condition, well fitted, thoroughly greased, and of sufficient size to permit of wearing woolen socks. (*c*) That the wearing of rubber boots for periods longer than a few hours be discouraged. Troops should be warned of the disadvantages of this form of footgear. Rubber boots always ventilate badly and remain moist after removal. In drying, they should be wiped out upon the inside after removal of the inner sole, and then hung by the inside straps suspended with the feet down. Neither puttees nor leggings will be worn under boots. (*d*) That there are available at all times suitable rooms set aside for use as drying chambers and that this space be of such arrangement and size as to adequately provide for the drying of all footwear or other clothing. (*e*) That the feet of all are vigorously rubbed at least once each day, and preferably with some animal fat, such as tallow or whale oil. (*f*) That active foot exercises be indulged in at frequent intervals, and from time to time that this be supplemented by removal of shoes and socks, with subsequent drying and massaging of the feet. (*g*) That special efforts be made to discover men who are suffering from corns, ingrown nails, blistered, or inflamed feet. Any one of these conditions alters the gait and thereby decreases efficiency and increases the tendency to "trench foot." All such cases should be placed under the surgeon's care without delay. (*h*) That every effort be made to reduce to the lowest possible minimum the necessity of the men performing duty with their feet in mud and water; this is frequently only a question of trench drainage and the elevation of "duck boards."

5. Since an ample supply of woolen socks is a primary need, arrangements will be made for the delivery of dry socks to the men at the front and for the return of wet ones to the drying rooms, thereby insuring to each man at least one change a day.

6. Before marching into a forward area, company commanders will make the necessary inspections of their command to see that all shoes are well fitting, in good repair, and properly "dubbined," and that each man has at least three pairs of serviceable woolen socks upon his person. At this time all members of the command will be warned against too tightly applied puttees. This danger is particularly prominent during wet weather, since dry puttees properly applied, which subsequently become wet, shrink 3 per cent of their length.

7. Since the lack of nourishment in general, and hot foods in particular, strongly predisposes to "trench foot," the responsible commanders will make suitable arrangements for the supply of hot food to the men. Food containers for bringing up hot food will be provided, and cookers and kitchens will be placed in localities suitable for supplying food and drinks. There will be served each day to all men in the forward areas not less than two hot meals, preferably one at midday and one between midnight and 5 a. m.

8. Plans for improvising and constructing field cookers, kitchens, clothes driers, or other special arrangements found necessary to properly carry this order into effect will be furnished upon application to these headquarters.

9. Foot powders and the various oils, greases, or ointments to be used in the prevention and treatment of "trench foot" and other diseases of the foot will be furnished by the Medical Department. The necessary supplies for application to boots, shoes, etc., will be supplied by the Quartermaster Corps.

10. The proper requisitions to meet the needs of this situation will be prepared and forwarded without delay to the various supply department depots for filing.

Subsequent to the promulgation of this order whale oil and grease in general came to be looked upon with disfavor; they made a coating which prevented the moisture from getting away from the skin.[7] It was thought that oil should be used only when gum boots are not available or when it is impossible to remove the gum boots for long periods at a time.

TREATMENT

The treatment of trench foot as practiced in the American Expeditionary Forces was based largely upon the work of Raymond and Parisot, of the French Army. The methods to be followed were published in Memorandum No. 4, Army Sanitary School, A. E. F., in the fall of 1917, the essentials of which were as follows:[7]

Edematous stage.—Foot baths with green soap and water. Large hot fomentations consisting of camphor 1 part, sodium borate 15 parts, boiled water 1,000 parts. The gauze compresses should be covered with an impermeable material (oiled silk or oiled paper) and should extend well above the upper limits of the edema. The most strikingly early effect of this treatment is the relief from pain, permitting men who have been unable to rest because of the pain to drop promptly off to sleep.

Blister stage.—Blisters larger than one-half inch in diameter should be excised and their gelatinous floors wiped away with a pledget of sterile cotton. On the bare surface thus produced place aseptic compresses of camphor 30 parts and ether 1,000 parts. Over these compresses the fomentations used for the edematous stage are placed and continued in use until after the disappearance of the edema, when the camphorated ether will suffice.

Slough stage.—The treatment outlined above will be adequate usually to prevent the formation of sloughs. When sloughs are present, however, loosen them by the camphor-ether compresses and alkaline camphor fomentations for the purpose of gaining access to the affected tissues beneath. Surgery is to be avoided except when the sloughs are hard, whereupon incise through them down to the grumous layer beneath, avoiding blood letting, then apply the compresses. The cautery should not be used.

The use of potassium iodide gave surprisingly good results in the elimination of pain in trench feet,[7] its action being almost specific.

Trench foot strongly predisposes to tetanus; consequently each patient suffering from trench foot should receive a dose of antitoxic serum that should be repeated at weekly intervals until the lesions become healthy in appearance.

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CHAPTER XII

WOUNDS OF SOFT PARTS [a]

Following the disastrous practice in the early months of the war of abstention from surgical intervention, it was for a time considered sufficient to remove projectiles and superficially clean the wound channel. Experience soon showed the inefficiency of these procedures. This tentative period lasted nearly two years, 1914 and 1915. In 1915 the method of "débridement" was initiated; in 1916 it was practiced, and in 1917 and 1918 it was elaborated and improved. This advance was dependent upon careful observation of the pathological factors involved in wounds produced by projectiles.

In wounds of the soft parts the muscles offer little resistance to the impact of a projectile and are extensivley lacerated even in many cases where the external wound is insignificant. Pathogenic organisms find an excellent culture medium in the devitalized tissues. A large variety of organisms flourish in war wounds and both anaerobic and aerobic bacteria grow at an active rate after a latent period of a few hours after the infliction of the wound. The habitat of these microorganisms is chiefly in the lacerated muscular masses.

According to Borst,[1] there are three zones in gunshot injuries of soft parts. The first, or innermost zone is represented by the wound channel or wound cavity, which is filled with necrotic tissue, extravasated blood, foreign bodies, and shreds of torn muscles. Next comes the zone of direct traumatic destruction, with cauterization of tissue. This is of variable width, according to the physical and morphological peculiarities of individual tissues and projectiles. Bacteria find the best possible culture-medium in the necrotic or seminecrotic tissue. In the third, or outer zone, the tissue is not necrotic, although greatly reduced in vitality. The fact has come to be definitely appreciated that all accidental wounds must be considered as contaminated, and this is especially true of gunshot wounds. With this knowledge of wound pathology it became evident that physical measures would best insure disinfection and that chemical measures should be regarded as accessory; also that the prospects for success from the use of these measures lie in employing them early, when the organisms which have been introduced into the wound are still superficially situated along the wound tract and have not extensively multiplied. Physical disinfection consists in ablation of necrotic tissue and removal of foreign bodies. This method, known as débridement, constitutes the greatest advance from a surgical standpoint that was developed in the recent war. It not only saved many lives but enabled many wounded soldiers to return to the front after a relatively short period of disability.

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[a] The statements made in this and the following chapter concerning the treatment of wounds of the soft parts and joints are based upon articles by the writer in: *Surgery, Gynecology and Obstetrics*, Chicago, 1918, xxvii, 289–311 (with B. J. Lee and P. A. Dineen); *Journal of the American Medical Association*, Chicago, 1919, lxiii, 383–388; *Annals of Surgery*, Philadelphia, 1919, lxx, 266–286; Oxford Surgery, 1921, V, 715–775; Keen's Surgery, 1921, VII, 557–589.

Notwithstanding the superior results derived from débridement, objections were raised that valuable tissues might be needlessly sacrificed, and especially that suppuration often occurred in spite of excision. Such failures following wound excision led to the utilization of other agents in the fight against infection, especially fluids for irrigation, having in mind both mechanical, solvent, and bactericidal properties.

All the customary antiseptics were utilized early in the war. Morestin [2] recommended equal parts of commercial formol, glycerin, and alcohol. Gaudier [3] utilized methylene blue in alcoholic or watery solution, 1: 1000.

It is noteworthy that many antispetic agents which are highly efficient in the test tube, for example bichloride of mercury, show less efficiency in the wound. Moreover, most antiseptic agents damage not only the bacteria but also the tissues, especially when used in strong concentrations, so that the surviving organisms find an excellent culture medium for their growth in the changed or necrotic tissues.

The many antiseptics which were recommended showed striking limitations in their efficacy, and great expectations were raised by the introduction of Dakin's solution, about the middle of 1915,[4] approximately the same time as extensive débridement began to be used. Carrel recommended that the new antispetic be injected into the wound channel.[5] The results were not highly successful, and thereafter Carrel regarded Dakin's fluid merely as the supplement to the operative procedures for the purification of contaminated wounds. The success of the Carrel method [5] depends largely upon aseptic details, especially thoroughness, gentleness, and cleanliness in dressings, and repeated flushings of the wound surfaces.

In many cases a prompt and careful operation is sufficient and need not be supplemented by instillation of Dakin's fluid. Yet in infected wounds most surgeons consider that Dakin's fluid in continuous irrigations or interrupted instillations constitutes by far the best method of wound treatment. But some have not observed superior results from Dakin's fluid as compared with the ordinary antiseptics, and consider the bactericidal action of this antiseptic as exaggerated, the results being due to the irrigation and the solvent properties rather than to its bactericidal properties.

The ideal treatment of war wounds, as based on experience gained in the World War, consists in complete excision of all devitalized tissue, followed by the application of immediate suture or secondary suture, according to conditions existing in a given case. When there is good reason to believe that little or no cause for infection is left, as when the whole tract has been excised and the wound appears healthy throughout, suture may be applied. This primary suture is performed either layer by layer or in bulk, the important point being to leave no dead spaces. Drainage is injurious rather than useful. Some operators, before closing the wound, irrigate it with ether, weak tincture of iodine, or salt solution.

When there is doubt as to the condition of the wound, primary suture must be omitted. The excision having been made as completely as possible, dressings are applied and suture performed subsequently if no infection fol-

lows. The indications for such delayed suture are to a large extent dependent upon the quantitative and qualitative estimation of bacterial flora in the wound. This is determined by smear and culture. It has been shown that in the absence of streptococci and with few other organisms a wound can usually be sutured safely. According to the time when delayed suture is done, a distinction is usually made between "delayed primary suture," if it is done within five days after the initial operation, and "secondary suture," if it is performed a longer time afterwards. But the real distinction between delayed primary suture and secondary suture is one of wound repair rather than of time. Delayed primary suture is one in which the edges can be approximated and will unite without excision of tissue. Secondary suture is one in which the epidermis has grown inward and must be excised for proper union. In late secondary suture dense granulation tissue must also be excised.

A very important point for the successful outcome of primary sutures is the interval between the infliction of the wound and the performance of the operation; this interval should be reduced to the shortest possible time. In the beginning, wounds were sutured primarily only when the wounded were operated upon within the first 12 hours, but later primary sutures were successfully applied at the end of 36 up to 48 hours after the infliction of the injury. At first only wounds of the soft parts were sutured, then articular wounds, and finally selected compound fractures. Immobilization of the damaged region is indispensable to a successful outcome of the operation.

It is generally conceded that the first primary sutures were performed in July of 1915, by René Lemaitre.[6] From July, 1915, to July, 1917, in 1,046 primary sutures, he had 944 complete cures, 39 partial cures, and 13 failures. Gaudier,[7] in November, 1916, also advocated this method. The procedure began to find more general adoption but not without giving rise to much controversy. In November, 1916, Tuffier[8] stated that, on the basis of official statistics, primary suture fails in 34 per cent of the cases. Dupont,[9] in March, 1917, published 49 cases of primary suture, including 4 sutures of articular wounds, with only 5 failures, only 1 of which was serious. Pierre Duval,[10] in October, 1917, sutured 1,058 of 1,230 wounds, with 86 per cent of complete cures in six weeks. For wounds which are not primarily sutured he recommended suture in three to five days. By Gross, Tissier, Houdard, Di Chiara, and Grimault,[11] 759 sutures were applied from July 23 to September 10, 1917, with 675 primary unions, 47 partial and 37 total failures;[b] i. e., 88 per cent success. Marquis, Descazals, Luquet, and Morlot[12] published results of their work during a period of attack; in the four days of this attack they sutured 500 wounds, including 133 bony and 34 articular wounds. The total mortality was 6.5 per cent, and 36 per cent of the wounded were discharged as convalescents 50 days after the infliction of the wounds. From July, 1917, to February, 1918, Lemaitre[6] performed 1,618 primary sutures, with 1,555 complete cures, 44 partial cures, and 19 failures.

The chief methods and agents which were employed for combating infection in war wounds are mentioned, although it is not feasible to discuss all of

[b] By complete failure is meant necessity for removing all stitches; by partial failure, superficial infection necessitating the removal of a few stitches.

them in this chapter: Débridement;[13] the Carrel-Dakin method;[5] dichloramin-T;[14] hypochlorous acid preparations, Eusol and Eupad;[15] hypertonic solutions or lymphagogic agents (Sir Almroth E. Wright);[16] salt pack (Col. H. M. W. Gray);[17] magnesium chloride (Delbet);[18] collargol;[19] Bipp (Rutherford Morison);[20] iodated starch;[21] flavine;[22] brilliant green;[22] methyl violet (pyoktanin);[23] magnesium sulphate;[24] sunlight[25] and ozone;[26] acetozone;[27] vaccine and serum treatment of infected wounds;[28] Delbet's pyoculture;[29] introduction of living anaerobes (Donaldson's method);[30] vuzin (Morgenroth and Tugenreich);[31] Vincent's powder.[32]

OPERATIVE TREATMENT

During the World War the wounded usually were received at the evacuation hospitals in from 4 hours to 24 hours after the receipt of injury, but during periods of battle activity the delay was sometimes much greater. They presented various degrees of shock, hemorrhage, laceration of the soft parts, and associated lesions. Frequently the wounds were multiple. They contained pathogenic microorganisms and in most cases foreign bodies. When admitted few of the wounds showed evidence of gas bacillus infection.[33]

Operative treatment is indicated for the majority of the wounded as soon as possible after the receipt of the injury. Each hour increases materially the danger from infection. Cases that could be saved within 14 hours are often lost after 24; wounds that could be closed successfully within 8 hours often become the site of infection and gas gangrene, resulting in amputation or death if left untreated for 18 hours.

After the arrival of the patient at the hospital, expedition in the surgical treatment must be effected by the help of a well-organized routine. The first essential is the careful sorting of cases at the admission tent. Patients presenting a considerable degree of shock should be left undisturbed on their stretchers and sent to the shock ward. They must first be treated for the shock, and operation deferred until reaction is evidenced by a rise of blood pressure. The chief exceptions to this rule are cases with cranial wounds, abdominal wounds, and sucking thoracic wounds. Walking cases and slightly wounded cases are referred to the dressing ward or to the service for slightly wounded. Of the remainder the majority demand X-ray examination and early operation. The dressings are removed and the wounds carefully examined. Those whose condition does not contraindicate it are bathed. Cases with active bleeding, with sucking thoracic wounds, with penetrating abdominal wounds, with fractures of the femur, with penetrating wounds of the knee, and with multiple wounds, receive the first attention. Cases which have reacted from shock may be taken at any time. Cases with uncomplicated wounds of the soft parts are, in general, cared for after the more urgent cases.

The success of operation depends largely upon the thoroughness of the roentgenologist's examination and the accuracy of his findings. Experience proved that his report should be made on the patient's card according to a definite system. It should include the anatomical site, the size of each foreign body in millimeters, the depth in millimeters, and the position of the part at the time of observation. For example: 1. Right thigh: F. B. 10 by 15 mm.;

80 mm. under point marked on skin; limb in extreme outward rotation. 2. Left leg: no F. B.; fracture both bones, middle third; much comminution.

The operator thus visualizes the condition more accurately than if the report were made in fractions of an inch, or if some relative term were employed. "Millimeter" is employed to avoid error and confusion.

In times of great activity some cases must be operated upon without X-ray examination. They should be selected carefully and should comprise those in which apparently a foreign body is not present or in which the foreign body is superficial.

The patient should always be examined by the surgeon before anesthesia is begun. In wounds of the extremities the surgeon should determine whether there is a nerve lesion and an arterial pulse. Apparently innocent wounds of the trunk may in reality be very serious. The possibility of intrathoracic or intraabdominal involvement should always be borne in mind. Cases in which the genitourinary tract may have been injured demand examination of the urine.

The preparation of the patient usually is done in the operating room on an extra table while the preceding operation is being completed. The wound is protected with gauze, the part shaved thoroughly, and scrubbed with soap and water over a wide area. Application of chemicals may follow. A common procedure is to cleanse with ether and then apply tincture of iodine. It is important to prepare a wide field and, in wounds of the extremities, to encircle the limb. The part is draped economically with towels and sheets.

A general anesthetic should be employed except in rare cases. Nitrous oxide-oxygen, administered by an expert anesthetist, is the least harmful. It should be the anesthetic of choice for patients in a condition of shock, gassed cases, and thoracic cases. Ether, however, is employed in routine cases. Minor operations may often be performed under primary anesthesia. Local anesthesia is rarely used.

For convenience of discussion wounds of the soft parts may be subdivided as follows: 1. Wounds by fragments of shells, grenades, or bombs. *a.* Fragment retained; penetrating wounds. *b.* Fragment not retained; perforating, plaie en séton, through-and-through wounds, or gutter wounds. 2. Wounds by bullets—rifle, pistol, or machine gun. *a.* Bullet retained; penetrating wounds. *b.* Bullet not retained; perforating, plaie en séton, through-and-through wounds, or gutter wounds.

A fragment of shell or grenade is of high velocity, irregular in shape, and with sharp edges. In contrast to a bullet it carries with it pieces of clothing and skin into the tissues. Because of its irregular shape it exerts a destructive effect upon the tissues which thus form an excellent medium for the development of the microorganisms carried in from the clothing and skin. After a latent interval of six hours or more both aerobes and anaerobes proliferate rapidly and penetrate more deeply into the tissues. The local changes and the later systemic effects depend upon the character of the microörganisms and the tissue resistance.

A bullet at close range exerts a marked explosive effect; during the major part of its flight, approximately from 500 to 1,500 yards, it penetrates the

soft parts with little destruction of the tissues; at long range it loses its steady spinning movement and causes mutilation and laceration. In the majority of cases of perforating bullet wounds the missile passes like a stiletto through the clothing and tissues. Infection may not result because the projectile carries no clothing into the wound and penetrates with little laceration and traumatism of the tissues. When such is the case operation is usually not required, since the few organisms which are present have not the proper environment for growth. Under certain conditions, however, when the appearance and feeling of the part suggest considerable hemorrhage or destruction of tissue, perforating wounds by bullets must be treated in the same manner as those made by fragments of shell. The rule is not to operate upon perforating bullet wounds with punctate wounds of entrance and exit and with little or no ecchymosis, swelling, or tension of the soft parts.

DÉBRIDEMENT

The general plan or aim of surgical treatment is the prevention or limitation of infection, the early closure of the wound, and the preservation or reestablishment of function. The first indication is to obtain a clean wound. This is accomplished, primarily, by débridement [c] of tissues—that is, by free incision and excision of injured and contaminated tissues and by the removal of the foreign material carried by the missile into the wound.

The principle of this procedure may be visualized by considering a typical case of a wound of the soft parts with a tract from the skin to the interior of the muscles, containing a fragment of shell and pieces of clothing along its course, and having for its walls lacerated muscle. Pathogenic organisms are present throughout this tract. The devitalized, pulpified walls of the tract furnish an ideal medium for the growth of bacteria. One can readily imagine that immediate wide excision of such a tract as a whole, including removal of the devitalized skin, subcutaneous tissues, aponeurosis and muscle, together with the shell fragment, clothing, and microorganisms contained within the tract, will leave a healthy aseptic wound, provided the skin adjacent to the wound has been properly prepared and the operator has employed a technique comparable to that used in clean operations. To obtain an aseptic wound is the ideal desired, though it is doubtful whether this is actually achieved in any case. But, however skeptical one may be as to the total eradication of microorganisms under the conditions which prevail in these wounds, many wounds after operation undergo repair as if aseptic, and cultures and smears made from them are often sterile.

Even during times of greatest activity débridement should be properly carried out and the best possible technique observed. The temptation to relax in these respects during periods of stress should be resisted. The time saved by careless work is not sufficient to warrant the additional risk incurred; only rarely is it justifiable to substitute incision and drainage for débridement in recent wounds.

The closure of the wound may be carried out by immediate or primary suture, delayed primary suture, or secondary suture.

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[c] This term is used to signify both the incision and excision of devitalized tissues, and removal of foreign body.

Technique

The skin incision, when possible, should be made parallel to the long axis of the limb. This permits wide exposure of the underlying tissues and renders subsequent suture less difficult. A transverse incision should rarely be employed. In the case of a deep transverse perforating wound it is better to make two longitudinal incisions and work inward from each rather than make a transverse incision with division or excision of considerable muscle tissue. In the former case suture is usually readily done at an early date, whereas in the latter primary suture is often impossible because of the difficulty of uniting the severed muscle. Even when this is accomplished the sutures frequently tear out and allow retraction of the muscle with resulting dead space and breaking down of the wound. When the transverse wound has not been closed primarily, or has reopened, secondary suture is delayed and is more difficult. The functional result is also less favorable on account of the transverse section of the muscle.

Transverse incisions should be employed in the extremities only in superficial wounds involving the subcutaneous tissues or with very superficial involvement of muscle. In the gluteal region and on the trunk the incisions, in general, should be in the direction of the fibers of the underlying muscle. Occasionally, as in deep, transverse, through-and-through wounds of the calf, a long median incision may be employed advantageously; the tract is exposed in the middle of its course and débridement is carried out from this region in both directions. The skin wounds of entrance and exit are excised by small elliptical excisions and the wound edges approximated.

The operation itself consists in the free excision of all tissues with which the foreign body has come into contact and all devitalized tissue, except structures such as nerves, large vessels, and bones, whose removal would interfere with the function of the part and cause permanent disability. Free excision, however, does not mean ruthless, blind butchery of the parts, but rather, careful, intelligent dissection, with liberal removal of such parts as should be removed, and with equally scrupulous preservation of such parts as may be left with safety.

The wound itself, with all contused skin, is excised by removing an elongated ellipse of skin. No healthy skin should be sacrificed on the sides of the ellipse, as it is important to conserve as much skin as possible in the transverse plane of the limb to facilitate suture. This is especially important in the forearm. There is no advantage in attempting a débridement through a short incision. A deep débridement demands a long incision. The skin incision must always be vertical to the skin surface; the tendency to bevel the incision should be avoided, as this interferes materially with satisfactory suture.

Lemaitre[6] prefers to begin with a short incision, say of 5 or 6 cm., and to increase it as the need arises. He does not hesitate to extend the ends inward or outward or to transform the incision into a flap.

When there are two wounds one or two incisions may be employed as already described. Similarly when the foreign body has taken a transverse or oblique course, penetrated a considerable distance, and lodged in the tissues,

two incisions may at times be used to advantage, one over the foreign body and one to excise the wound of entrance, both being used for excision of the tract.

After excision of the skin wound the instruments should be discarded or washed in alcohol. The skin edges are widely retracted and the subcutaneous tissues removed as far as there is evidence of laceration or contamination. It is not necessary, however, to remove all blood-infiltrated subcutaneous tissue. In general, the fingers are kept out of the wound and the dissection made with instruments. Good exposure of every plane by retraction is essential, the edges being rolled outward with toothed retractors or some form of clamp, such as the Allis forceps.

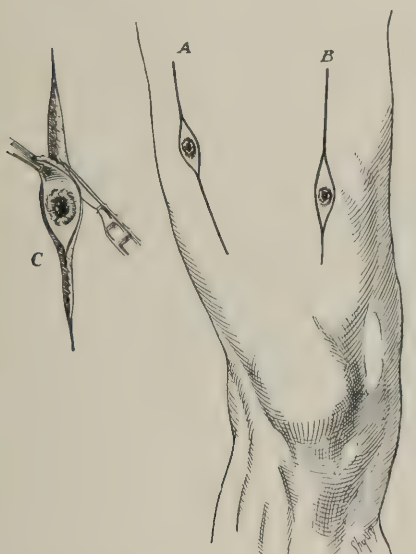

FIG. 159.—Débridement. Excision of the external wound

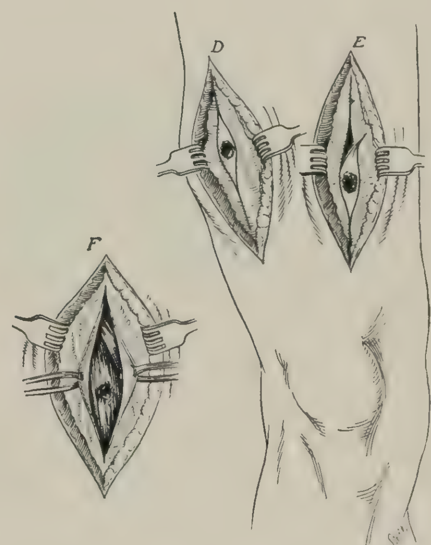

FIG. 160.—Débridement. Excision of the aponeurotic layer

The aponeurosis is treated in the same manner as the skin—that is, by a long straight incision with removal of the wound by a relatively narrow ellipse. (Fig. 160.) The aponeurosis is of great value in secondary sutures in the lower extremity and shoulder, and, therefore, should not be ruthlessly sacrificed. It must be emphasized that liberal excision of aponeurosis or skin is not necessary because it is not in these tissues that infection ordinarily originates or develops. The aponeurosis should be widely retracted and muscle planes exposed. It is this tissue that favors infection. All traumatized and devitalized muscle must be removed. This demands excision for a distance of 0.5–1 cm. on all sides of the tract. The dissection is made parallel to the fibers of the muscle; a long, relatively narrow ellipse is removed so that the sides tend to fall together after the excision. The dissection should be made by planes, muscles should be identified, and the situation of nerves and large vessels should always be borne in mind. The tract should be followed by sight, not by probing; for this purpose a reflecting headlight is indispensable.

If the tract is lost between muscle planes, often slight flexion or extension of the limb will bring it into view. Careful hemostasis is necessary at all stages. Sponging of blood should be done by pressure and not by rubbing, because the latter method may carry organisms from an infected to a clean part of the wound and may cause a small tract to be lost to view.[6] The foreign body should not be extracted until reached in the dissection, otherwise the parts fall together and the tissues immediately beyond the body, which often contain clothing, may not be adequately excised. When the excision is complete all exposed muscle must look healthy, contract when pinched with forceps, and ooze when snipped with scissors; otherwise its vitality has been diminished to such a degree as to favor gas bacillus infection. At times the finger must

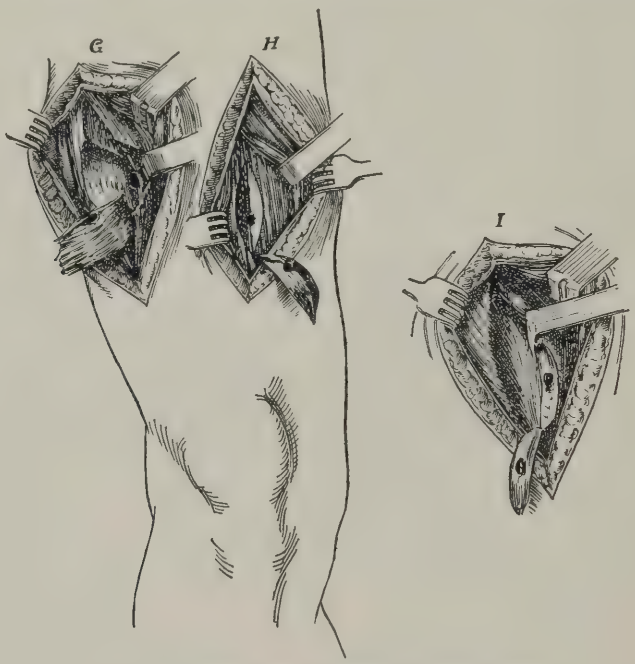

FIG. 161.—Débridement. Excision of injured mucles

be introduced to search for the foreign body, but, as a rule, in cases where the track is lost or where for other reasons difficulty arises in locating the foreign body, fluroscopy should be employed.[d] If this fails, the tissues should not be blindly torn up, but after a careful search one should desist, leaving the wound open and removing the foreign body subsequently, after more careful X-ray localization or under the screen. When the deep tissues are so markedly infiltrated with blood as to suggest the possibility of constriction of the muscles under the overlying fascia, this fascia must be incised so as to free the muscles from internal pressure.

When the fragment or tract is in proximity to a large vessel, as, for instance, the brachial vein, the vessel should be inspected and, if traumatized, should be treated by ligation and excision of the contused portion; otherwise

[d] The Bergonié vibreur was used to advantage at La Panne and elsewhere.

secondary hemorrhage is likely to occur. If there is danger of gangrene resulting from ligation a primary suture should be performed and the case watched with particular care. In the case of a small lateral wound Lemaitre[6] advises repair of the vessel wall by suture if the neighboring tissues are healthy. Ordinarily, however, it is best to ligate the vessel about 1 cm. above and below the vascular wound and to excise the intervening portion. Though sudden and unexpected hemorrhage will occasionally confront the surgeon, the absence of an arterial pulse below the lesion and the widespread infiltration of the soft tissues about the wound usually warn the operator in advance of the presence of a vascular lesion. The importance of having a tourniquet at hand at all times is obvious.

Care should be taken to avoid injury to nerves by careless dissection. A severed nerve should be united, and if possible the nerve should be buried within muscle tissue. When preliminary examination shows that a nerve

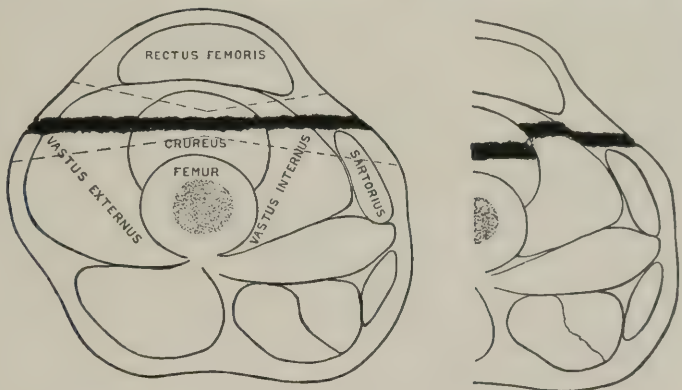

FIG. 162.—Change of position of wound tract from changed position of limb

has been injured, it should be exposed above or below the tract early in the operation to avoid traumatization during débridement.

When the excision has been completed all hemorrhage should be controlled. As little catgut as possible should be buried. The wound should be irrigated with saline or Dakin's solution. Ether has been extensively employed for irrigation of wounds after débridement, but it probably has not sufficient merit to warrant its use. Lemaitre [6] employs 5 per cent tincture of iodine, after drying the wound, to fix the superficial microorganisms. One of its disadvantages is the slight secretion of turbid serum due to its action upon the superficial cells of the wound. We have not been able to note any advantages from its use.

If the wound is left open vaselined gauze is placed over the exposed skin edge and subcutaneous tissues in order to prevent the dressing from adhering and to lessen oozing and pain when the dressing is removed. Gauze soaked in Dakin's solution is placed loosely in the wound in such a way as not to cause retention of secretions. Dry gauze is applied over this and the dressing kept in place with a bandage. This is the routine treatment for cases which are to be

evacuated early. Cases which are to be retained may be dressed similarly, or Carrel-Dakin treatment, if indicated, may be begun at once.

The indications for Carrel-Dakin treatment may be summarized as follows: If the operator feels that débridement is satisfactory and that the wound is likely to be susceptible of suture in a few days chemical disinfection is unnecessary and Carrel-Dakin treatment is not used. If, for any reason, such as incomplete excision of tissues or the large size of the wound, it seems probable that the wound must be left open for a week or more, Carrel-Dakin treatment is advisable. Even clean wounds that are left open for a considerable time always become infected, but the use of Carrel-Dakin treatment will prevent or limit the infection. When infection has occurred the use of Dakin's solution will do much to control and terminate it. Under these conditions the treatment is essential.

FIG. 163.—Wound by shell fragment two weeks after débridement and primary suture

PRIMARY AND SECONDARY SUTURE

There are two conditions under which war surgery is performed at the front: First, relatively quiet periods; second, times when military activities are acute. In quiet times a thin but fairly continuous stream of wounded are passed back to the forward hospitals, but only occasionally, as after a raid, does congestion occur. The wounded usually can be operated on almost as soon as they are received; there need be no hurry, and the patients may be carefully watched after operation. The aggregate of such cases along a wide sector in quiet periods reaches formidable figures.

The ultimate aim of treatment is to restore the soldier to full activity, with complete restoration of function, in as short a time as possible. Obviously, one of the conditions of such restoration is the repair of the wound. During quiet times early closure of the wound may be undertaken successfully in a large proportion of cases. Great benefit thereby accrues both to the patient

and to the service. But the long relatively tranquil periods also are of use in affording an opportunity for study and demonstration as to what may be done and what should be done under the varying conditions of war surgery. As a result of such study of technical methods and tissue repair, rules may be formulated and safely enforced for the treatment of the wounded during periods of greater activity.

It must be recognized, therefore, that local conditions such as the degree of battle activity, alter materially the indications for suture, particularly for primary suture, in the advanced area.

The following is an outline of the general principles and technic of the three varieties of suture of war wounds, namely, primary suture, delayed primary suture, and secondary suture in wounds of the soft parts:

FIG. 164.—Perforating shell wound, left thigh, the same missile penetrating right thigh and fracturing right femur. All wounds closed by primary suture. (Heuer, Keen's Surgery)

PRIMARY SUTURE

Débridement having been completed, the choice of treatment lies between primary suture and leaving the wound open. If ideal conditions, that is, early and thorough débridement, have been approximated and the case can be watched for some days, primary suture may be made. Otherwise, the wound is left open and sutured subsequently. Obviously, the decision in a given case, as to whether primary suture may be made, must be attended with much uncertainty; a mistake may be costly to the patient. In active periods, as in an offensive, when there are many wounded, the exigencies of a service demand haste in the primary operation, and the patient must be evacuated, passing from the operator's control soon after the operation. Under these conditions, primary suture should not be considered. It may be employed, therefore, only in quiet periods and in hospitals where patients may be retained for observation

FIG. 165.—Multiple, penetrating wounds of back, soft parts, closed by primary suture. Lower left wound "failure." (Heuer)

FIG. 166.—Long perforating wound of thigh, with opening of knee joint, closed by primary suture. (Heuer)

The advantages of primary suture are obvious; the disadvantages consist chiefly in the danger of closing within a wound, especially within a wound imperfectly débrided, noxious microorganisms, particularly anaerobes of the types which produce gas gangrene. A resulting gas bacillus infection or a

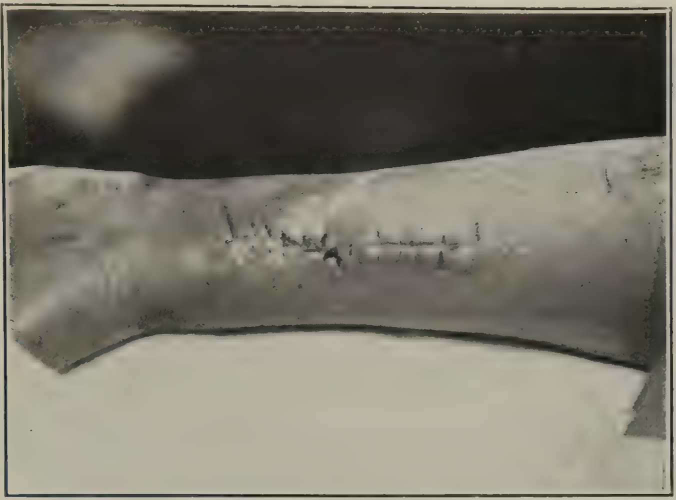

FIG. 167.—This and Figure 168 show perforating wounds of forearm with fracture (see fig. 169), two weeks after débridement and primary suture

pyogenic infection in a few cases will counterbalance many successful closures. The only means of rendering primary suture safe is by extreme operative care

FIG. 168

and thoroughness, thoughtfulness and judgment in the selection of cases, and, finally, scrupulous watchfulness for some days after the operation.

When the circumstances are such as to warrant primary suture the following considerations must be weighed in each case in deciding whether or not

suture is indicated: (1) The interval between the receipt of the wound and the operation; the type of tissue and situation of the wound. Thus, wounds involving the muscles of the calf, thigh, or gluteal regions should not be closed as a rule after a longer interval than eight hours. In these muscular parts gas bacillus infection is prone to occur and to result disastrously. In other muscular parts the time often may be extended to about 12 hours. In wounds not involving muscles the time may be further extended. It must be understood, however, that such rules based on the time between the injury and the operation are not absolute and have been advanced only as a suggestive working basis. Wounds of the face and scalp are regularly sutured. Wounds of the hands should, as a rule, be sutured. Extensive wounds of the feet should, as a rule, be left open, treated by the Carrel method, and closed subsequently.

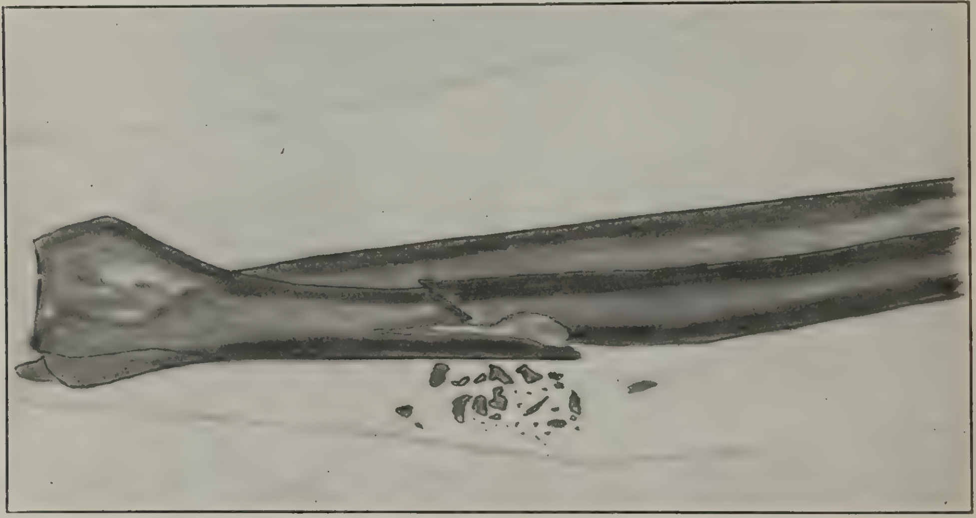

FIG. 169.—Outline of X-ray, Figure 167

(2) Extensive laceration of the soft parts or the presence of a large shell fragment or of considerable clothing in the tissues shortens the time within which primary suture may safely be made. (3) Conditions which demand haste in the operation, and therefore militate against thorough and painstaking débridement, preclude primary suture; for instance, multiple wounds, condition of shock, or period of a rush. (4) Diminution of the vitality of the parts, especially as a result of vascular lesions, precludes closure; for instance, wounds of the calf with the posterior tibial artery sectioned, or marked infiltration of the tissues with blood. (5) As has been emphasized, primary suture must not be made unless the patient can be watched carefully for days thereafter. Accordingly, it was a general rule in the American Expeditionary Forces that during active periods no primary suture of wounds of the soft parts should be made except in wounds of the scalp, face, or hands, as enumerated above.

Technique

Thorough débridement is essential, and aseptic technique must be observed throughout the operation. Hemostasis must be complete. The wounds

should be washed sufficiently to remove blood clots and loose fragments of tissue. Many operators, after drying the wound apply ether to the wound surfaces; this, however, is empiric. Lemaitre [6] applies tincture of iodine to fix residual microorganisms. It is questionable, however, whether the ether or the iodine are factors of importance. The muscles and aponeurosis are approximated with interrupted catgut. As little and as fine catgut should be introduced as will approximate the tissues and obliterate dead spaces. The skin and subcutaneous tissues are closed with interrupted silkworm gut. Drainage should be avoided. If employed, the drain should be removed as soon as possible, in general, within 24 hours. In some cases, especially in deep wounds of muscular parts, a few strands of silkworm are advantageous as a means of obtaining subsequently a culture from the interior of the wound. At the first dressing the silkworm should be removed and cultures taken, and if hemolytic cocci are found the wound should be reopened. After the dressing has been applied the part should be immobilized.

Partial primary suture of wounds of the soft parts has nothing to recommend it; it is often harmful; it should therefore rarely be employed.

A wound which has been closed by primary suture should be examined within 24 hours; moreover, the general condition of the patient should be carefully watched. These precautions can not be too strongly urged. If they are observed, there is not much danger of fatal infection; if they are neglected, avoidable fatalities will occur. It is, in general, the failure to recognize the development of gas bacillus infection or pyogenic infection as early as one should, and the unwillingness to admit failure of the primary suture and the necessity for complete reopening of the wound and free excision of gangrenous muscle, that cause the fatalities.

When gas bacillus infection develops after primary suture its onset is suggested usually by local tenderness or spontaneous pain in the wound after 12 hours, or by changes in the general condition of the patient which should be watched for and immediately recognized. These changes can be noted, as a rule, in about 18 to 24 hours after the operation. They are rapid pulse, peculiar gray appearance of the face, and moderate rise of temperature, for instance, to 101°. The condition, if left, rapidly becomes worse, and six hours later the systemic symptoms are often greatly accentuated. The patient becomes profoundly toxic, with high temperature, delirium, and dyspnea. Locally, in typical cases, the part is swollen, tender, tense, and often bronzed in patches; the face, however, may look and feel normal. A tympanitic note on finger percussion, as emphasized by Lemaitre,[6] can often be demonstrated. Crepitation is frequently present. On opening the wound, or perhaps not until the aponeurosis has been opened, bubbles of gas and thin, brownish fluid exude; the typical rotten meat smell is noted, and the involved muscle shows the characteristic appearance and lack of vitality, notably, an unhealthy salmon color, friability, and failure to contract on pinching. Cultures in these cases show various anaerobes, especially *B. welchii* (perfringens), often associated with pyogenic organisms.

DELAYED PRIMARY SUTURE

The distinction between delayed primary suture and secondary suture is one of tissue repair rather than of time. Delayed primary suture is one in which the edges can be approximated and will unite without excision of tissue. Secondary suture is one in which the epidermis has grown inward and must be excised for proper union. This is, in general, about one week. In late secondary sutures dense granulation tissue must also be excised. The determination as to when a wound may be sutured depends on bacteriologic findings and clinical observation. It must be emphasized that the cooperation of a bacteriologist is indispensable in making a decision as to the indications for delayed primary and secondary sutures. The practical function and indisputable importance of the bacteriologist in war surgery lies in this. In the

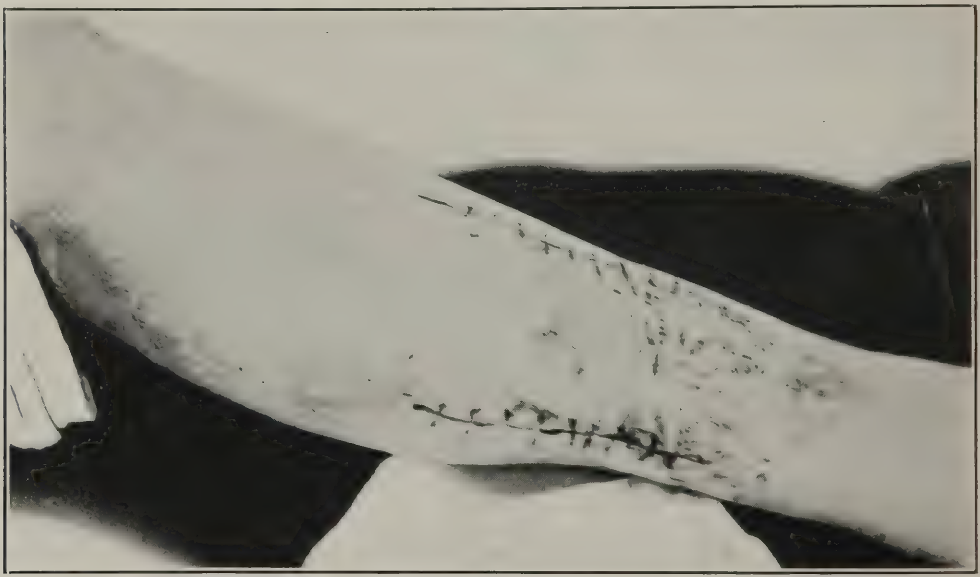

FIG. 170.—Large penetrating shell wound, internal aspect of leg, closed by retarded primary suture. (Heuer)

consideration as to whether a wound is suturable or not reliance must be placed chiefly on cultures, the important feature being the determination of the presence or absence of hemolytic cocci. For this a routine blood-agar examination is essential.

Bacterial counts are far from exact, yet they give an indication as to the degree of bacterial contamination of a wound, especially the progress from day to day, and are of value especially for one untrained in estimating clinically the indications and contraindications for suture.

From 18 to 24 hours after the original operation of débridement or excision of tissues the wound is dressed and a culture and a smear are made. A report is returned as soon as possible. If no organisms are found, suture is indicated. If hemolytic cocci are present, suture is not considered. In the absence of hemolytic cocci, if the wound is clinically suturable, the presence of a few

anaerobes or other organisms (approximately one in two fields) does not contraindicate suture. A considerable number of organisms of any kind indicates the necessity for caution. Suture, in that event, should be delayed and a culture and a smear repeated at the following dressing.

Delayed primary suture is usually made within six days after the primary operation. The advantages of this method are the practical elimination of the danger of gas bacillus infection and the marked lessening of the danger of pyogenic infection. The disadvantages are the possibility of postoperative contamination of the open wound and the subjection of the patient to a second operation, with the attending discomfort and danger of postoperative complications, such as pneumonia. These disadvantages, however, do not equalize the risk incurred by primary suture in doubtful cases.

FIG. 171.—Large perforating wound of thigh, closed by primary suture. (Heuer)

Technique

All dressings of wounds after the primary operation should be made according to the Carrel-Dakin technique. The anteoperative preparation of the wound for delayed primary suture consists in painting the skin with tincture of iodine, after thorough cleansing as in the routine dressing. Some operators also paint the wound surfaces. The details of suture are the same as for primary suture.

SECONDARY SUTURE

The following routine is generally followed: After 48 hours, at the daily dressing, a culture and a smear are made. The first report, therefore, contains the approximate number of organisms per field and the varieties of organisms. Thereafter, a smear is made every two days. It is also advisable to make a culture occasionally. Care must be taken not to touch the skin surface in making the smear, since skin contamination vitiates the value of the report. From the smear a bacterial curve may be plotted according to Carrel's plan. When the organisms in two successive counts are few, that is, approximately one per two fields, and a culture shows an absence of hemolytic cocci, the wound is considered susceptible of secondary suture, except when the wound has contained hemolytic cocci at any time. In that case careful cultures are made

from granulation tissue and from the discharge from all parts of the wound; and absence of hemolytic cocci should be established by two successive negative cultures before suture is made. It has been observed that streptococci are prone to lie dormant in small numbers but to flare up and cause virulent infection after closure of the wound.

FIG. 172.—Wound, posterior aspect, right thigh; compound comminuted fracture of femur. Two weeks after débridement. Treated by Carrel method

Technique

The preparation is the same as for delayed primary suture. Lemaitre [c] distinguishes two varieties of secondary suture: (1) Secondary suture of the skin. The incision surrounds the new epidermis along the wound edges. A healthy normal skin edge must be present for successful suture. The skin is freed by undermining in all directions as far as necessary in order to approximate the edges with the minimum tension. This separation is made in the plane immediately superficial to the deep fascia. Only dense scar tissue or

projections of granulation tissue are removed from the wound. The deep fascia is then approximated with interrupted catgut when possible; usually this may be done in the thigh and shoulder, but rarely in the leg, arm, and forearm. The skin and subcutaneous tissues are closed with silkworm gut. Considerable tension may be allowed, far more than we are in the habit of permitting in civil practice. If little skin was removed at the original operation

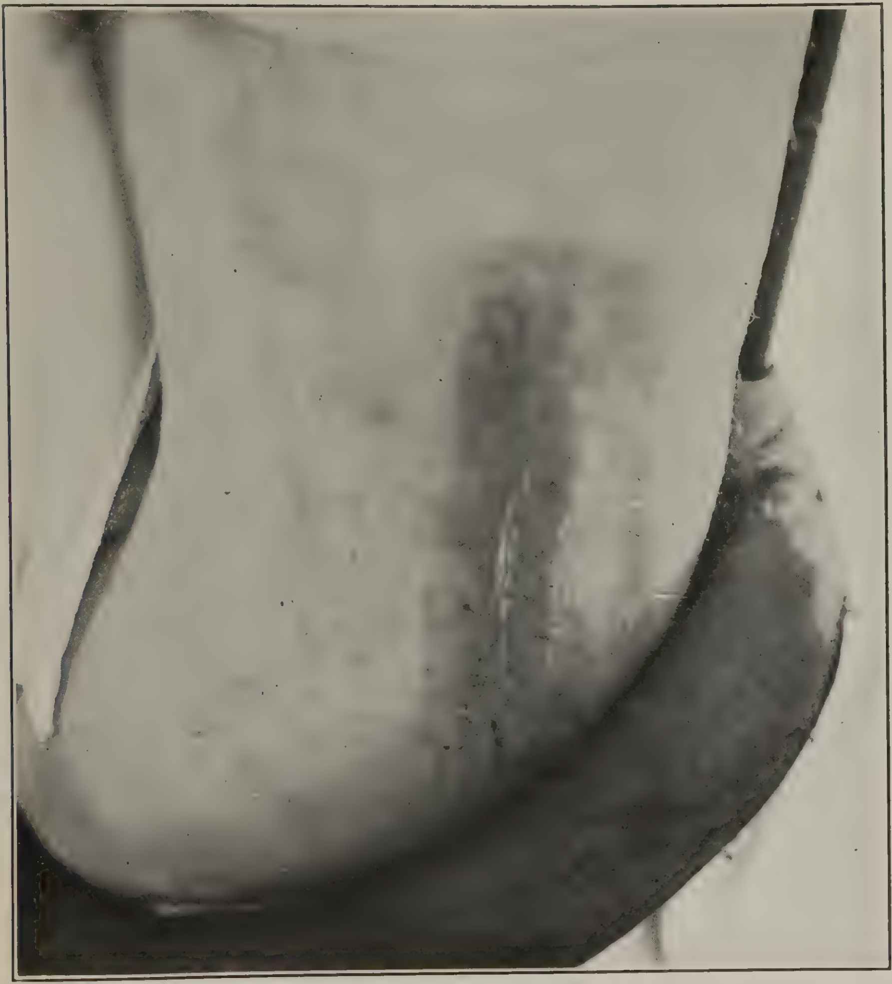

FIG. 173.—Same wound as that shown in Figure 172, two weeks after secondary suture

the skin stretches in a short time, tension is relieved, and good union results. The result of suture is directly proportionate to the degree of tension. If there is extreme tension infection may be expected. It is surprising, however, how well most of these wounds do, even after some infection. After the suture is completed a dry dressing is applied with considerable pressure and left undisturbed, if conditions warrant, for about eight days, after which sutures are removed[7]. (2) Secondary suture reconstruction. The granulation tissue

and scar tissue are removed from the entire wound and all layers are reconstructed by suture.

When two longitudinal wounds are on the same transverse plane, with considerable loss of tissue in each, one wound can usually be closed completely and the other closed in part. A dry dressing is applied and the wounds are left for about eight days, after which the sutures are removed. The unclosed portion then presents a flat, clean, granulating surface.

WOUNDS OF THE FACE

Wounds of the face must be considered independently. However severe, extensive, and dirty the wound, virulent pyogenic infection and gas gangrene are not prone to develop. This feature makes it possible by timely operative intervention to avoid in most cases the gruesome mutilations which were so often allowed to occur in the early days of the war. The rule which may be safely followed is to repair wounds of the face as soon as possible after the receipt of the injury without general excision of tissues. The wound is cleaned thoroughly, and only such tissue is removed as is definitely devitalized. The mucous membrane is then closed and the skin wound sutured. Such wounds unite quite regularly. Secondary plastic operations are made in order to improve unsightly scars, to reconstruct the angle of the mouth, etc. The frequently associated fractures of the maxillæ should be treated by a surgeon-dentist. In his absence the original operator should conserve as far as possible all fragments of bone.

WOUNDS OF THE HAND

In general, the soft parts should be studiously conserved; when conditions warrant, primary suture should be made and early active motion enforced Wounds by shell fragments with retained foreign bodies should be operated upon. Wounds caused by very small fragments may be left unopened, especially if bone, tendons, or joints are uninvolved.

In extensive wounds of the hand slow, painstaking cleansing by conservative débridement is necessary. Tendons are cleaned carefully; unopened tendon sheaths should not be entered. If practicable, divided tendons are sutured. If suture is not possible, severed tendons should be united with others so as to obtain the best functional result. Even extensive wounds of the hand should be closed if they have been carefully and thoroughly treated. If a dead space is present a drain should be introduced. Plastic operations with sacrifice of a finger and excision of a metacarpal are advisable if the danger of infection can thus be diminished.

WOUNDS OF THE FOOT

Ample longitudinal incisions are necessary except for perforating wounds near the margin of the foot, in which case a transverse incision is employed, laying open the whole track. In the anterior part of the foot it is best to expose the whole track by incision through the web between the toes. Conservation of the digits is not necessary to the same extent as in the hand. Usually primary suture may be made in slight wounds. Extensive wounds of the foot should be left open and treated with Dakin's solution.

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CHAPTER XIII

WOUNDS OF JOINTS

The experience gained in the World War resulted in striking changes in the treatment of wounds of joints caused by projectiles. During the early years of the war poor results usually followed these lesions by reason of an undervaluation, on the part of surgeons, of the resistance to infection which the synovial membrane of a joint offers, a failure to comprehend the proper operative procedures, and the universal employment of prolonged immobilization. But in the last 18 months or 2 years methods of treatment were adopted in the allied armies which gave results far superior to any that preceded.

PREOPERATIVE MANAGEMENT

Although attention must be focused upon the operative treatment as the most important factor, the preoperative management of the patient can not be disregarded. As soon as possible after the receipt of the wound a first-aid dressing should be applied. Active hemorrhage, as a rule, can be controlled by a light pressure bandage over the dressing. This failing, a tourniquet may be applied. It must be emphasized, however, that a tourniquet is a dangerous accessory. It should be applied close to the wound, and should be removed as soon as possible. It is essential in joint wounds that the part be immobilized before the patient is moved. In a large proportion of cases, especially when associated with fracture, traction also should be applied.

For transportation in the advanced area the following splints are advisable:[a] For fractures involving the knee joint the Thomas leg splint and the hinged half-ring modification (Blake-Keller) are applicable. A litter bar attached to the stretcher supports the injured limb during transportation. For slight injuries of the knee joint without marked effusion, also for injuries to the ankle and tarsus, the Cabot posterior wire leg splint is advisable. This splint provides immobilization only. For injuries of the hip joint the Thomas traction leg splint or the long Liston splint should be used. For injuries involving the shoulder and elbow the hinged modification of the Thomas arm splint is useful when fixation and traction are desirable. The advantage of this splint is that the injured limb may be brought to the side of the body for recumbent transportation, which can not be done with the ordinary Thomas arm splint. For the smaller joints, which need only immobilization, the ladder splint or the wooden coaptation splint may be used.

The wounded are received at a front hospital, for instance, a mobile hospital or an evacuation hospital, from about 4 hours to 24 hours or more after the receipt of injury. Their previous treatment, besides a first-aid dressing for the wound and a temporary splint for immobilization, has consisted in the administration of antitetanic serum and appropriate treatment for those pre-

[a] Manual of Splints and Appliances for the Medical Department of the United States Army, 1917.

senting a condition of shock. The patients on arrival at the hospital present various degrees of shock, hemorrhage, laceration of soft parts, and associated lesions. The wound or wounds contain pathogenic microorganisms and, in most cases, foreign bodies. The devitalized tissues provide an admirable medium for the growth of microorganisms which, however, lie dormant for a time, roughly from 6 to 8 hours, after which they become active and infection progresses with variable rapidity and intensity.

INDICATIONS FOR OPERATION

All wounds of joints by projectiles, except certain perforating (through-and-through) wounds by bullets, should be operated upon. Perforating bullet wounds are not operated upon if the wounds of entrance and exit are punctate and there is no evidence of displacement of fragments or of hemorrhage. Punctate wounds are made by a bullet of high velocity with no explosive effect and no deflection during its course through the limb. In such cases the bullet cuts through clothing and tissues, carrying few organisms into the wound and producing little destruction of soft tissues or comminution of bone. Experience proved that under these conditions infection rarely occurs even when a fracture is present. Therefore these cases do not demand immediate operation. They should, however, be carefully watched, and distention of the joint should be treated in the manner described in the after-care of operated cases.

In all other cases operation should be performed as soon as possible after the receipt of the injury. Delay increases the danger of and from infection by reason of the bacterial types which are usually present and the characteristics of their growth and penetration in the tissues. But before operation certain preliminary precautions are essential. Thus: A careful examination by the surgeon of the patient and his lesions is essential. The general examination should be sufficiently thorough to preclude the possibility of overlooking a serious associated lesion. The degree of bone involvement and the presence and position of retained foreign bodies should be established by the X ray. The surgeon should satisfy himself as to whether there is or is not a nerve lesion; this is especially important in the upper extremity. He must also examine for arterial lesions, especially in wounds of the lower extremity; the presence or absence of the anterior and posterior tibial pulse should be noted. Moreover, the time elapsed since the wound was received, the situation of the wound, the extent of injury to the soft parts, and the general condition of the patient are factors which must be weighed before a plan of action can be decided upon.

ROENTGENOLOGIC EXAMINATION

The success of the operation depends largely upon the thoroughness of the roentgenologist's examination and the accuracy of his findings. His report should be made according to a definite system. The following routine has been found the most satisfactory:

Anatomic site and size of each foreign body in millimeters, depth in millimeters, position of the part, if it is not in the anatomic position; bone lesions. For example: "Right knee, F. B 10 by 15 mm., 50 mm. in depth, under the point marked on the skin, the limb being in 45 degrees outward rotation; comminuted fracture of internal condyle; no displacement."

PREPARATION OF PATIENT

The local preparation is usually done in the operating room on an extra table while the preceding operation is being completed. The wound being protected with gauze, the surrounding skin is shaved and scrubbed with soap and water. Application of chemicals may follow. The usual procedure is to cleanse with ether, following this with the application of tincture of iodine. It is important to prepare a wide field; even to encircle the limb. The part is draped with towels and sheets.

A general anesthetic should be employed save in exceptional cases. Nitrous oxide-oxygen, administered by an expert anesthetist, is the least harmful. It should be the anesthetic of choice for patients in a condition of shock. Ether, however, is employed in routine cases.

After careful consideration of the factors enumerated above the surgeon should proceed as far as possible in accordance with a definite plan. The choice between amputation and conservation of the limb should be made, if possible, before the operation is begun, so that the patient may be spared futile efforts to save the limb. Irreparable mutilation of the soft parts, excessive comminution of bone, wounds of the main vessels of the limb, especially in the lower extremity, irremediable injury to essential nerves, or advanced gas bacillus infection, are the main features which call for the consideration of amputation. The condition of the patient is often the deciding factor. But the results of conservative treatment are sufficiently good to weigh in its favor in cases of doubt. Amputation is indicated in a relatively small percentage of cases.

Conservative operative treatment of recent wounds of joints has for its object, first, the prevention of infection; second, the preservation of function.

The important features are thorough débridement, complete closure of the joint, and early movements.

The adoption of these principles by our Allies in the war of 1914–18 followed three well-defined stages: 1. Débridement; drainage; irrigation with antiseptic solutions; immobilizations. 2. Débridement; Carrel-Dakin treatment of the joint; immobilization. 3. Débridement; lavage of the joint with Dakin's solution or ether; joint suture, with drainage of the joint for about 24 hours; immobilization; passive movements and massage in 8 to 10 days.

During the development of these methods the results improved progressively, but were not satisfactory, as was demonstrated by Depage [1] at La Panne, Belgium, where these procedures were conscientiously carried out and the results analyzed. It was recognized early in the war that the main features which are of importance in the treatment of battle casualties of other types, particularly early operation and thorough débridement, are likewise indicated in the treatment of wounds of the large joints. But, whereas in other types of wounds it is often advisable to leave the wound unsutured and to supplement the operative treatment by chemical sterilization before proceeding to a final closure, it was found that an unsutured joint in general did not progress satisfactorily. In such cases postoperative chemical sterilization could not be depended upon, and the introduction into the joint of drains, such as rubber

tubes, was found to result disastrously, in that they often introduced infection and caused pressure necrosis, thus diminishing the resistance of the synovial membrane and articular cartilage to infection. Moreover, they failed to accomplish their purpose, that is, to drain the joint. Immediate closure of the joint by suture was found to be essential to success. Therefore the surgeon must rely upon the primary operation for the prevention of intra-articular infection, which is the immediate aim of conservative treatment. The important factor being the débridement of tissues, the principles of this, as applied to wounds of the soft parts, bones, and cartilage, must be fully understood.

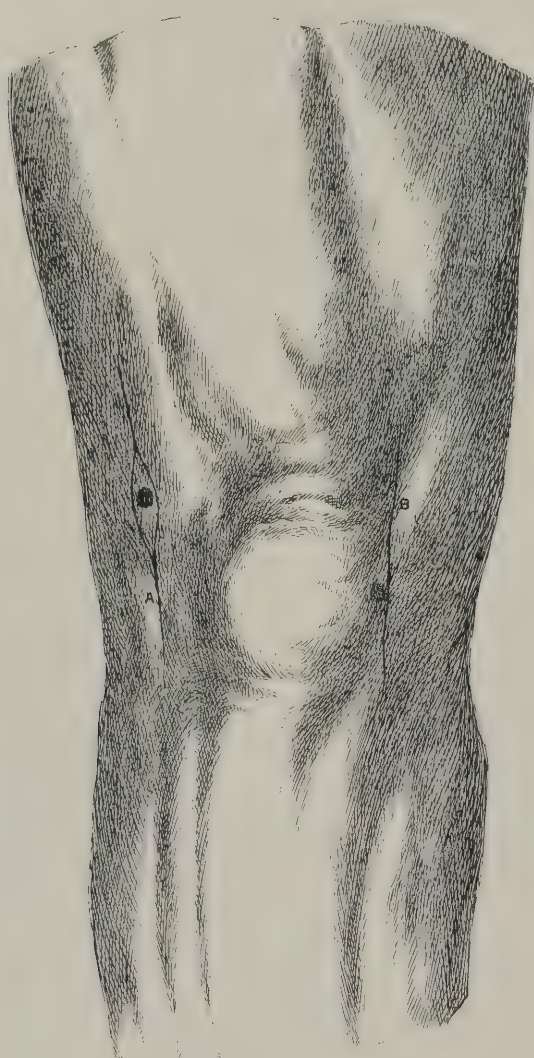

FIG. 174.—Gunshot wound of knee. A, Incision for débridement of wound of entrance; B, incision to expose retained foreign body. (See fig. 175.) (Keen's Surgery)

TECHNIQUE

The details of a conservative operation may be summarized as follows: Complete débridement of the tract of the projectile through the soft parts and bone; removal of foreign bodies; thorough irrigation of the joint; absolute closure of the joint by suture; primary or delayed closure of the superficial parts according to the rules laid down for primary suture of the soft parts alone; finally, early active motion.

The incision or incisions must be placed so as to permit not only thorough débridement of the soft parts but also free access to the foreign body and involved bone. Though no rules can be formulated, longitudinal incisions are to be preferred when practicable; however, the position of the wound or wounds and that of the foreign body are, in general, the determining factors. The primary incision includes the wound of entrance and is often supplemented by a second incision. In a perforating wound the second incision usually includes the wound of exit; in a penetrating wound it is placed in such position as to expose a retained foreign body which otherwise would be inaccessible. The incisions must be of sufficient length to give adequate exposure. (Fig. 174.)

Through these incisions débridement of the soft parts (fig. 175) proceeds as in operations elsewhere. The technique is practically the same as for wounds of the soft parts alone, but the refinements of technique in respect to asepsis and adequate exposure must be fully observed, and traumatization of the synovial membrane should be reduced to a minimum.

It is sometimes difficult to identify the opening in the capsule or even to determine whether the joint has been penetrated. This difficulty is met most often in the case of small perforating and penetrating wounds with little or no bone involvement in which a fragment of shell has either perforated the limb, traversing the joint in its course, or has penetrated the joint and lodged in it or in adjacent tissues. But, after the capsule has been exposed in the débridement, the orifice into the joint must be demonstrated before the joint is opened. Great care should be exercised to avoid opening a joint that is uninvolved, and, similarly, not to neglect proper operative measures in a joint that is involved.

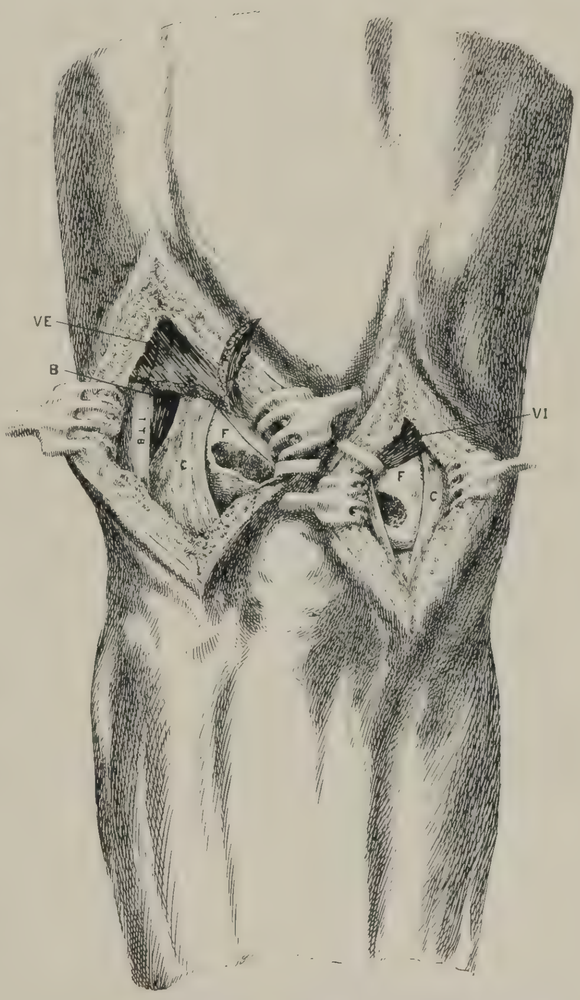

FIG. 175.—Gunshot wound of knee. Outer side: After débridement of wound and opening of capsule. Dotted lines indicate extent to which capsule has been opened. Inner side: Arthrotomy to reach foreign body in internal condyle. F, Femur, internal and external condyles, with gutter wound débrided; C, capsule; VE, vastus externus; ITB, iliotibial band; VI, vastus internus; B, biceps femoris. (Keen's Surgery)

The capsule and synovial membrane should be opened by a liberal incision with thorough elliptic excision of contused or contaminated tissue, conserving, however, all tissues that can be left safely. Foreign bodies must be removed. The subsequent steps depend upon the presence or absence of a bone lesion. If none exist, the joint is irrigated and closed; if a bone lesion is present, it must be appropriately treated before closure of the joint.

In all cases contaminated bone surfaces must be cleaned as thoroughly as possible; that is, treated on the principle of removal of contaminated tissue.

This is done with gouge, chisel, or curette, with the sacrifice of as little bone as possible.

An intra-articular wound of the bone or cartilage, such as a gutter, depression, or canal without complete fracture, constitutes the simplest type of lesion. The bone wound should be cleansed as above described.

When there is an injury to an articular surface consisting in a limited and incomplete separation of a layer of cartilage with a thin layer of underlying bone, it is advisable to remove the partly separated and poorly nourished cartilage, and with chisel, gouge, or curette to cleanse the surface from which it has been detached.

Where a fracture line has resulted in partial detachment of a large fragment of bone with its articular surface, but the fragment retains good contact with the soft parts, it is left after the tract has been followed and contaminated surfaces have been cleansed as thoroughly as possible. But under such conditions it is important that the fractured surfaces be left in close contact. An intervening space interferes materially with union, as Cotton emphasized years ago.[2]

If an attached fragment is to be removed, this should be done if possible by the subperiosteal method of Ollier, using the Lériche modification of the sharp Ollier elevator. By this method a re-formation of the bone is more probable.

In extensive involvement of the articular surfaces an effort should be made to save the joint, provided the conservable articular surfaces and soft parts are sufficient to warrant a reasonable hope of securing a useful joint. In this connection it must be borne in mind that stability is essential in the knee and ankle; that is, in the weight-bearing joints.

When there is such loss of the articular surfaces as to preclude obtaining a useful joint, resection should be elected. A classical resection should be done when stability and rigidity are desired, as in the knee; otherwise an atypical resection may be made.

The final steps of the operation in all cases are as follows: Complete hemostasis should be secured. The joint is then thoroughly washed with salt solution to remove blood clots, bone fragments, and débris. Some operators recommend that this be followed by lavage with ether under sufficient pressure to distend the joint. However, this use of ether is empiric; it is questionable whether it exerts any beneficial influence. The synovial membrane and capsule are closed with fine chromic gut which should be, as far as possible, extra-articular. When feasible, these two layers should be sutured independently. Complete closure of the joint without drainage is the invariable rule.

When there is such destruction of the soft parts that the edges of the capsule can not be approximated, if an attempt is to be made to save the joint, the defect in the capsule should be completely closed with muscle or fascia, using a pedunculated flap, if necessary. In a few cases in which this was impossible the writer has seen a partial closure made and the wound treated by the Carrel method, the aim being to close the joint subsequently by a plastic operation. He has not, however, seen this method successfully carried out without infection.

The soft parts overlying the capsule may be closed or left open for subsequent suture. If the ideal conditions—that is, early and thorough débridement—have been approximated and the case can be watched for some days, primary suture may be made; otherwise, the wound is left open and sutured subsequently. In active periods, as during offensive military operations, with a consequent large number of wounded, the exigencies of the service demand haste in the primary operation, and the case must be evacuated and pass from the operator's control soon after the operation. Under such conditions primary suture of the superficial tissues should not be considered; it may be employed only in quiet periods and in hospitals where patients can be watched. In this connection it must be urged that cases of wounds of the large joints, e. g., knee, should be included in the nontransportable class after operation, when conditions warrant their retention.

The advantages of primary suture are obvious; the disadvantages consist chiefly in the danger of closing within a wound, especially within a wound imperfectly débrided, pathogenic microorganisms. A resulting gas bacillus infection or virulent pyogenic infection in a few cases will counterbalance many successful closures; moreover, primary suture increases the danger of joint infection by inward extension of a superficial infection. The danger, however, is lessened if interrupted silkworm sutures, placed at rather long intervals, are employed for the approximation of skin and subcutaneous tissues.

If the soft parts are left open, vaseline-saturated gauze or other bland nonadhering gauze is placed along the edges of the wound so as to cover the skin edges and subcutaneous tissues. This prevents the dressing from adhering and lessens hemorrhage and pain on its removal. Gauze soaked in Dakin's solution is placed very loosely in the wound. It should be so adjusted as not to cause retention of secretions.

In cases in which there is an extra-articular lesion of bone in conjunction with a joint lesion, the joint is treated and closed as described; the extra-articular bone lesion is appropriately treated and the wound of the soft parts is left open. Every effort should be made to close such a wound by delayed primary suture, because prolonged exposure will often result in infection, and infection will secondarily involve the joint.

POSTOPERATIVE CARE

The ultimate aim of treatment is to restore the individual to full activity, with complete restoration of function, in as short a time as possible.

EARLY ACTIVE MOBILIZATION

It must be emphasized that early reestablishment of the function of the part is dependent upon early active mobilization. Before the war immobilization for a considerable period after operations upon joints was the usual practice. Complete loss of function, limitation of function, or delay in return of function frequently resulted.

Having in view the early and complete reestablishment of functions, Willems,[3] of Hoojstade, Belgium, urged that postoperative immobilization should not be employed, and demonstrated the correctness of his claims by

a series of brilliant results. Other surgeons were slow to accept his method to the extent of adopting immediate mobilization with the elimination of all splinting. But various operators practiced short periods of immobilization, and subsequently inaugurated movements at an earlier date than was their former practice. Moreover, as the beneficial results and relative freedom from complications became evident, they gradually approached and even followed Willems' plan. An example of the conservatism which prevailed may be illuminating. Thus, in 1917, Cook[4] advised "that when the object of treatment is mobility, and the asepticity of a case has been provisionally established—i. e., after the temperature has been normal for about a week—light

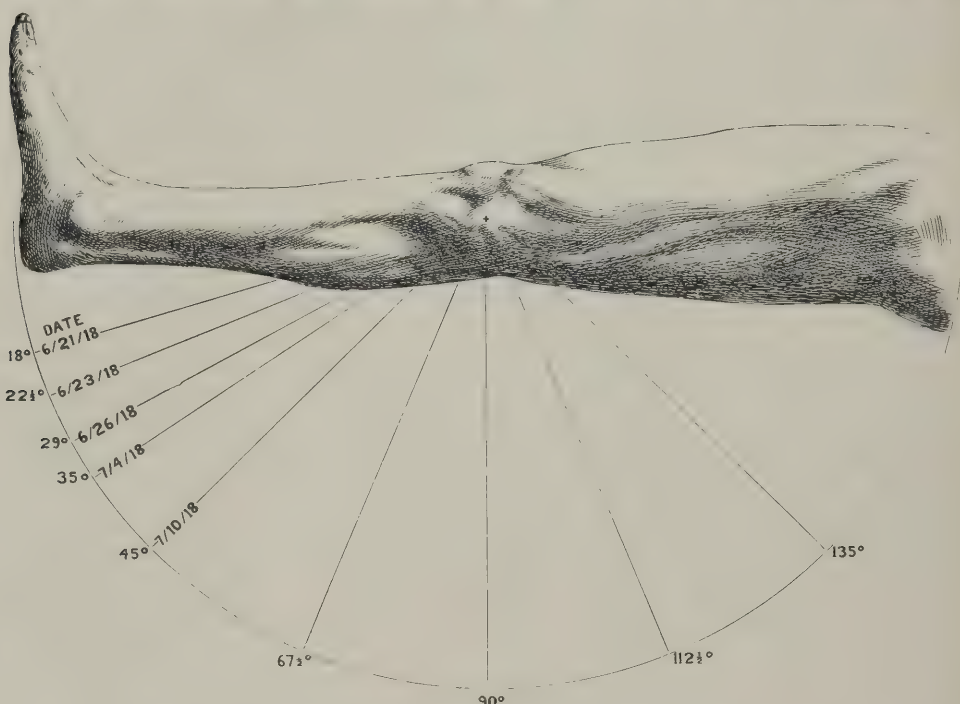

FIG. 176.—A convenient method of recording the range of motion. (Keen's Surgery)

movements are applied. Further treatment in this direction is regulated by absence of reaction and comparative freedom from pain."

The writer was taught the Willems method at La Panne in the winter of 1917–18. The method, however, was not at that time generally accepted, so in the early work with the American Expeditionary Forces at Evacuation Hospital No. 1 he was somewhat conservative in its application. In general, he employed a splint for a brief period, but enforced early movements whenever practicable. As a means of recording the range of motion he found it convenient to use a diagram (figs. 176, 177). The date is entered on the arc opposite the degree of motion.

Dowden[5] states without reserve that, owing to the practice of immobilizing joint lesions, thousands of British soldiers have been rendered cripples for life. In this respect views as to the treatment of joint injuries have under-

gone a radical change as the result of the experiences on an unprecedented scale in the recent war.

It may properly be urged that after operations for recent joint wounds immediate mobilization should be employed in all cases in which a fracture does not contraindicate, or the character of the wound of the soft parts is not such as to interfere with repair of the wound. The patient should be encouraged and directed to move the joint as soon as the operator feels that this can be done without interfering with tissue repair. For instance, following a transverse wound with removal or suture of the patella or after suture of an extensive wound of the thigh, a period of immobilization must be enforced. In the treatment of wounds associated with fracture, mobilization of the joint is not indicated if it is likely to interfere with alignment or union or promote excessive callus formation. But Willems [3] claims that constant mobility prevents the development of intra-articular callus and, therefore, is advan-

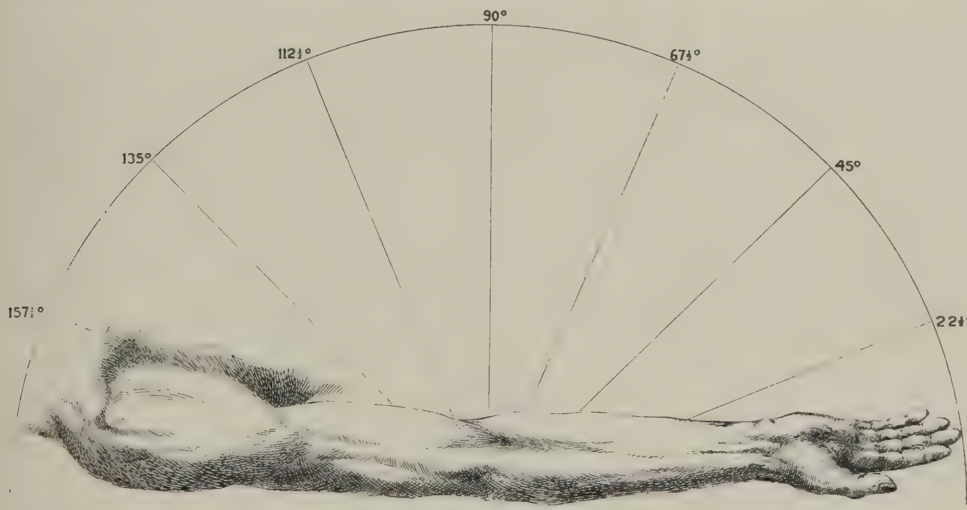

FIG. 177.—The same method as that shown in Figure 176 of recording motion in the elbow. (Keen's Surgery)

tageous rather than harmful. On the other hand, in the type of wound with little involvement of bone and soft parts, a splint should not be applied. The patient should flex and extend the knee as soon as he has recovered from the anesthesia. The movements must be active, not passive; they should be as extensive and frequent as feasible. Little pain is experienced if the movements are begun early. Supervision by a nurse for the direction and encouragement of the patient is essential. Willems [6] recommends that patients with little or no bone injury should be out of bed soon after the operation, even as early as the second day. In wounds of the lower extremity they are encouraged to walk, gradually increasing the amount from day to day. Crutches and cane are used at first, but are soon discarded. In the case of joints of the upper extremity patients are directed to scrub and sweep, gradually increasing the period of work. In cases with a bone lesion the patient is kept in bed for a longer period, the time being roughly proportionate to to the degree of bone injury. In cases associated with fracture they are

encouraged to get out of bed and use the limb as soon as this can be done without endangering alignment and union. Early use of the joint is essential for early restoration of function.

TREATMENT OF THE WOUND

A wound which has been closed by primary suture should be examined within 24 hours; moreover, the general condition of the patient should be carefully watched. These precautions can not be too strongly urged. If they are followed there is not much danger of fatal infection; if they are neglected, avoidable fatalities will occur.

Obviously, one of the conditions of early restoration of function is the repair of the wound; therefore, when the soft parts have been left open, the wound should be closed as soon as possible by delayed, primary, or secondary suture. The distinction between delayed primary suture (Duval) and secondary suture is one of tissue repair rather than of time. Delayed primary suture is one in which the edges can be approximated and will unite without excision of tissue; this is, in general, about one week. Secondary suture is one in which the epidermis has grown inward and must be excised to permit proper union. In late secondary sutures dense granulation tissue must also be excised from the surface of the wound and the skin must be mobilized. The determination as to when a wound may be sutured depends upon bacteriologic findings and clinical observation. The cooperation of a bacteriologist is indispensable in making a decision as to the indications for delayed primary and secondary sutures. In the consideration as to whether or not a wound is suturable reliance must be placed chiefly upon cultures, the important feature being the determination of the presence or absence of hemolytic cocci. For this a routine blood-agar examination is essential.

Bacterial counts are far from exact, yet they give an indication as to the degree of bacterial contamination of a wound, especially the progress from day to day.

Eighteen to 24 hours after the original débridement the wound is dressed and a culture and a smear are made. If no organisms are found, suture is indicated; if hemolytic cocci are present, suture is not considered. In the absence of hemolytic cocci, if the wound is clinically suturable, the presence of a few anaerobes or other organisms (approximately one in two fields) does not contraindicate suture. A considerable number of organisms of any kind indicates the necessity of caution. Suture in that event should be delayed and a culture and a smear repeated at the following dressing.

When a wound is left open for a considerable time cultures and smears are made at regular intervals. The reports contain the approximate number of organisms per field and the varieties of organisms. When the organisms in two successive counts are few, that is, approximately one in two fields, and a culture shows an absence of hemolytic cocci, the wound is considered susceptible of secondary suture, except when the wound has contained hemolytic cocci at any time. In that case careful cultures are made from granulation tissue and from the discharge from all parts of the wound; and absence of hemolytic cocci should be established by two successive negative cultures before

suture is made. It has been observed that streptococci are prone to lie dormant in small numbers and to flare up and cause virulent infection after closure of the wound.

Delayed primary suture is usually made in from two to six days after the primary operation. The advantages are the practical elimination of gas bacillus infection and marked lessening of the danger of pyogenic infection. The disadvantages are the possibility of postoperative contamination of the open wound, the subjection of the patient to a second operation, and some interference with the institution of early movements. However, these disadvantages do not equalize the risk incurred by primary suture in cases which can not be carefully watched.

All dressings of wounds after the primary operation should be made according to the Carrel-Dakin technique. The introduction of tubes to permit frequent chemical disinfection with Dakin's solution is indicated only in cases which are infected or which are evidently destined to be left open for a considerable time—that is, a week or more.

The preoperative preparation of the wound for delayed primary or secondary suture consists in painting the skin with tincture of iodine after thorough cleansing, as in the routine dressing. Some operators also paint the wound surfaces.

POSTOPERATIVE INFECTION

Superficial infection may require the removal of only a few stitches; more extensive infection of the superficial tissues requires reopening of the entire wound to the capsule. The wound should then be treated by the Carrel method and may be suturable subsequently.

If the joint becomes distended, and infection is suspected, it should be aspirated immediately and a culture made. The writer has seen turbid fluid containing diplococci aspirated from a distended joint on the third day after operation, and uneventful recovery follow; also much turbid fluid evacuated from between the sutures in the capsule on the second and again on the fourth day by pressure on the subcrural bursa. In the latter case the joint was markedly distended until the fourth day. Possibly, as a result of the distention, there was no limitation of motion at any time. This patient quickly regained full motion and in six weeks was back at the front, with perfect function.

If the patient's condition, the local examination, and the character or culture of the aspirated fluid indicate pyogenic infection, one or more incisions should be made at once. But if the original incision is so placed as to allow satisfactory drainage it should be reopened and the treatment for suppurative arthritis begun. Willems' method of drainage by active movements is here recommended. The important feature is to begin treatment early; no drains should be used; splints are dispensed with or arranged for support without joint fixation. Free mobility every two hours should be enforced by active movements so as to evacuate the joint. Early nonvirulent infections with little or no bone involvement usually do well. In severe or long-standing infections, especially with bone involvement, the treatment has not proved as satisfactory. The method will be described in detail in a later paragraph.

In two cases under the writer's care, where purulent intra-articular infection occurred and the joint was reopened, Carrel treatment was carried out for a few days and secondary suture of the joint was made successfully in eight days. The Carrel treatment is most appropriate in wide open joints for a short period and where the joint is opened soon after the infection has begun. Hughes and Banks[7] have obtained admirable results by its use, especially in the elbow and shoulder, and have been able to sterilize the wounds and perform secondary suture in a large proportion of cases.

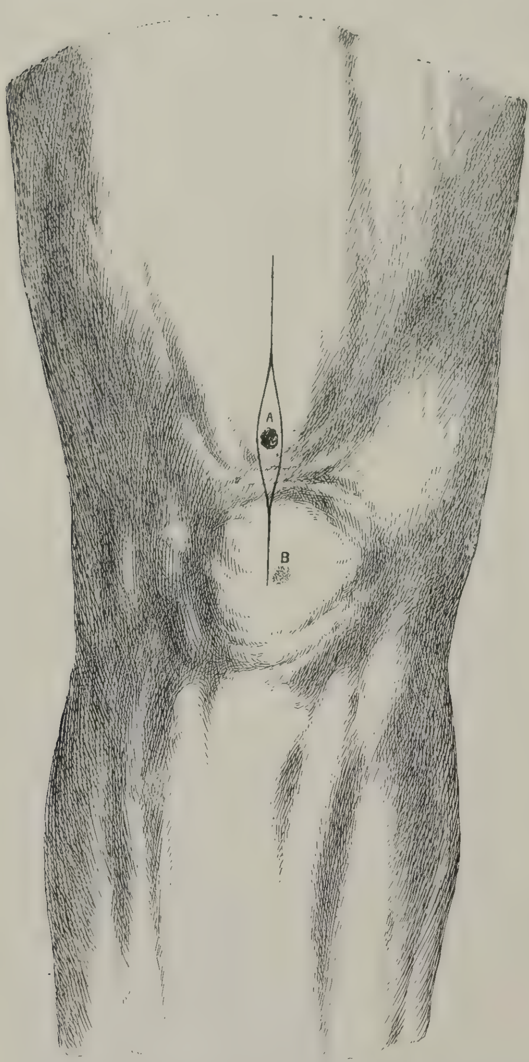

Fig. 178.—Gunshot wound of the knee. A, wound of entrance, incision for débridement; B, situation of foreign body. (Keen's Surgery)

KNEE-JOINT

Certain details which bear upon individual joints, especially the knee, must be emphasized. For the initial operation, lateral incisions are to be preferred; but, as stated above, the situation of the wound or wounds, and the position of the foreign body must, as a rule, be the determining factors. Occasionally the incision may be curved or even transverse, but division of the patellar tendon should rarely be made and then only when full exposure of the joint is essential, as when a foreign body lies in the region of the crucial ligaments. When the wound of entrance is above the patella the joint may be explored to a considerable extent through the wound of débridement. In one of the writer's cases a foreign body embedded low in the articular surface of the femur was brought into view above the patella by acute flexion of the knee. Removal of the foreign body and treatment of the bone injury were effected through this incision (figs. 178, 179).

The following are the usual procedures followed for the various types of bone injuries: (1) A small partially detached piece of articular cartilage should be removed; (2) articular cartilage with considerable bone, the whole attached to soft parts, should be left; (3) extensive comminution of a condyle which necessitates its removal demands resection. Removal of one condyle will

result in so much lateral mobility as to necessitate later resection. In the decision between primary resection and conservation of an imperfect joint it must be borne in mind that stability is essential in the knee; (4) where great disorganization of the articular surfaces exists immediate resection is indicated. Tuffier[8] affirms that this method of treatment forms one of the greatest advances made in the surgery of the joints, and has caused a large diminution in the number of amputations of the thigh. Lériche[9] advises that the tibia be nailed to the femur to prevent dislocation after resection. For this purpose Blake recommends two spikes, converging from each side of the tibia upward and inward into the femur. They are removed when union has taken place.

When the bone lesion is so extensive that resection would be necessary through the narrow shaft above the condyles, amputation is in general preferable.

Compound fractures of the patella should be treated by removal of completely separated fragments and preservation of large attached fragments which should be approximated if possible by suture. Complete removal of the patella should be avoided, since the functional result is poor. However, when the patella must be removed a flap from the quadriceps tendon should be attached to the patellar tendon, as advised by Murphy.[10]

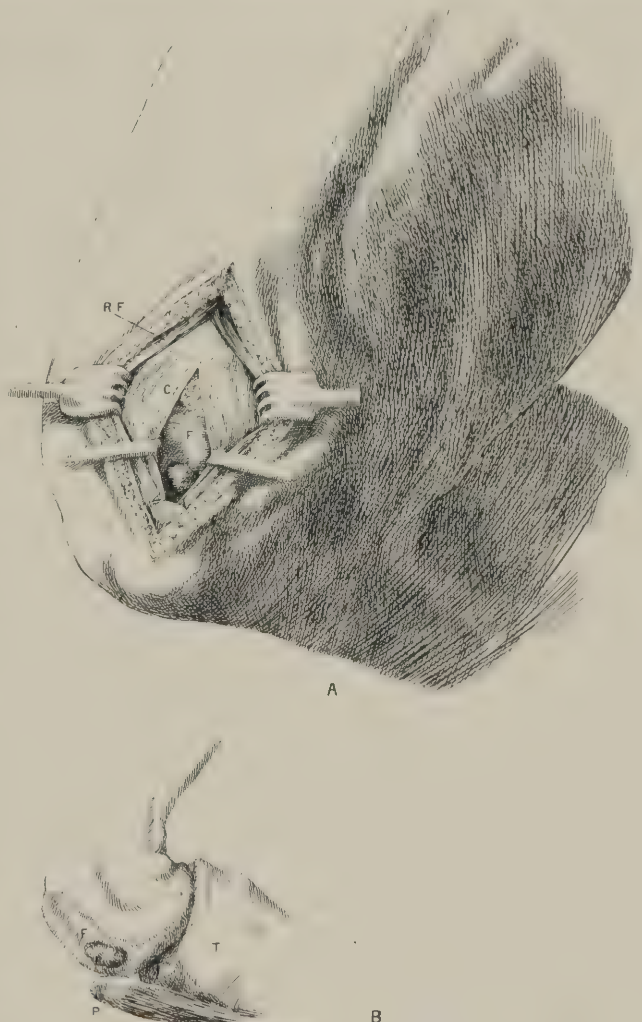

FIG. 179.—Gunshot wound of the knee, same as that shown in Figure 178. Incision in capsule after débridement. Foreign body exposed by acute flexion of knee. A: RF, Rectus femoris; F, femur articular surface; C, capsule. B: F, Femur articular surface; T, tibia; P, patella. (Keen's Surgery)

Much difficulty may be experienced when excision of a portion of the head of the tibia has been necessary. The defect in the capsule is difficult to close. When the loss of articular surface is slight it may be possible to supplement

the deficiency in the capsule by turning a flap of fascia from an adjoining part and suturing it in place so as to complete the closure. If the loss of articular surface is considerable, resection is usually necessary.

In compound fractures of the tibia in which the joint is not directly involved, but with one or more lines of fracture extending into the joint, intra-articular infection frequently develops. If hemarthrosis is marked, arthrotomy, irrigation, and closure are indicated in general, in addition to the operative treatment of the wound and the fracture. Every effort should be made to convert the compound into a simple fracture at an early date by suture under bacteriologic control.

In the cases which the writer observed in which an open knee joint was associated with a wound of the popliteal or femoral artery, amputation ultimately became necessary except in two instances. One of these was an open knee joint without bone involvement complicated by a wound of the popliteal artery. Arthrotomy and ligation of the popliteal artery (Jopson) were followed by a good functional result. The other was a case operated upon by Delrez. It was a penetrating bullet wound of the popliteal space, with division of popliteal artery and vein. The bullet was extracted under the method of Hirtz by trepanization of the condyle. Both vessels were doubly ligated. Mobilization was begun four days later. There was almost complete restoration of function in six weeks.

An analysis of a series of cases of wounds of the knee joint which were operated upon and followed by Jopson and Pool [11] affords approximately the average figures for this type of wound:

Total number of cases	34
Average time between receipt of wound and the operation (excluding one case of three days' duration) hours	11
Shortest interval do	3½
Longest interval do	26
Type of missile:	
High explosive shell fragments	25
Pistol	5
Rifle or machine gun	4
Penetrating wounds:	
High explosive	23
Pistol or rifle	2–25
Perforating wounds:	
High explosive	2
Pistol or rifle	7–9
Wounds with bone involvement:	
Femur	12
Femur and tibia	3
Femur and patella	6
Tibia	3
Patella	4–28
Wounds without bone involvement	6
Complications:	
Multiple wounds	10
Wound of main blood vessels	3
Femoral artery	1
Popliteal artery	1
Popliteal artery and vein	1
Contusion of peroneal nerve	2
Shock or hemorrhage, or both	4
Gas gangrene (preoperative)	2

Primary Operation

In all except two cases the joint was sutured primarily. In one case primary amputation was necessary, and in another an attempt was made to save a badly shattered limb, in which the wound of the knee joint was of secondary importance. This case came to amputation, but not for joint infection.

Primary amputation	1
Primary suture of joint	32
Primary closure of superficial wound	21
Delayed primary closure of superficial wound	4
Secondary suture of superficial wound	4
Evacuated before suture of superficial wound	2
Amputation for vascular gangrene before skin wound was sutured	1
Amputation for gangrene of foot in case in which joint and soft parts were not closed. Gangrene resulted from gaiter with traction for two days prior to admission (French soldier)	1
Total number of infections during stay in hospital	8
Infection of joint and soft parts	3
Infection of soft parts alone, severe, requiring reopening, Carrel treatment and secondary suture	1
Infection limited and superficial, requiring the removal of only one or two sutures, not interfering with primary wound healing	4
Evacuated within 24 hours (this case was amputated at the base, details are lacking)	1

While joint infection occurred in three cases, in only one did this result in ankylosis. In the others the infection was controlled by prompt reopening and Carrel treatment for several days. In both of these the joint and soft parts were sutured successfully after sterilization.

Secondary Amputations

In two cases amputation was required before evacuation. In neither was it done for infection; in one it was for gangrene following an associated wound of the popliteal artery and vein, and in the second for gangrene of the foot, the result of prolonged pressure by the anklet used in connection with the Thomas splint, which had been in place for two days before admission. In another case, evacuated 24 hours after operation, the record shows the limb was amputated later at a base hospital.

End Results

The average length of stay in the hospital was 26 days.

Deaths. Total number	2
Cause: 1. Multiple wounds, gas gangrene, retroperitoneal infection. 2. Multiple wounds, shock, gas gangrene.	
Amputations, primary	1
Amputations, secondary	2
Good functional result apparently assured at time of evacuation or from subsequent information. (Little or no limitation of joint movement, and a stable weight-bearing limb)	15
Fair result (partial limitation of motion after several months; good weight-bearing limb)	4
Poor result from standpoint of function (one complete ankylosis the result of infection; one secondary resection for weak joint)	2
Result as to function undetermined	7
One case evacuated within 24 hours, amputation at base	1–34

A review of the above results convinced us that a conservative policy in dealing with wounds of the knee joint caused by projectiles is strongly indicated. It was shown that infection can be avoided in the great majority of cases; that even when intra-articular infection develops, function can sometimes be preserved, or, if lost, that amputation is not inevitable; finally, that early and complete restoration of the joint offers the best chance for an early and complete restoration of function.

Mouchet and Pamart [12] reported the late results one year after early operations on 54 soldiers who had sustained wounds of the knee by projectiles, 49 being high-explosive shell fragments.

There were 39 per cent good results; 25 per cent fair results; 35 per cent bad results. They found that the greatest functional deficiency occurred in cases of arthrotomy for wounds with bony lesions. The worst results followed U-shaped arthrotomy.

SHOULDER

When resection is necessary for extensive comminution of the head of the humerus the subperiosteal method is strongly recommended by Lériche,[9] who urges that great care be taken to preserve the continuity of the capsule and periosteum. He advises that the end of the humerus be immobilized for a time in the glenoid cavity and that movements be undertaken very gradually in order to avoid a flail joint. Conservation of bone is important. The extensive resections which were done during the second year of the war resulted in almost useless flail limbs.

ELBOW

In the elbow the conservation of bone is an object to be especially aimed at; therefore classical resections are less often advisable than in the knee. The head of the radius and the capitellum can be sacrificed without material loss of function, especially if active motion is begun early. When the internal condyle must be removed function is less perfect and lateral mobility is to be expected, yet the result may be fairly satisfactory. In more extensive lesions, especially when there is such extensive comminution of the articular surfaces that resection is necessary, the choice must often be made between a movable flail joint and ankylosis in a useful position.

If resection is performed by the subperiosteal method, which permits regeneration of bone, even extensive resection of the lower extremity of the humerus may be followed by favorable results. Le Fur [13] believes that the bad results following this method are referable more to the destruction of the muscles and periarticular tendons than to the loss of bone. Lériche [9] urges subperiosteal resection when the mechanism of the joint is seriously disturbed: that is, when the trochlea or the articular surface of the ulna are badly involved. He states that callus forms rapidly, that anatomic and functional restitution are gradually brought about, and that in many cases within a year after complete resection there is perfect pronation, supination, and flexion, with marked solidity. He closes the wound by delayed primary suture under bacteriologic check and does not employ the Carrel treatment; the arm is put up in acute flexion and full supination; very limited and infrequent active movements are

begun in 8 to 10 days. He urges rigidity, and states that it is a flail joint and not ankylosis that is to be feared.

Unfortunately, under the conditions which prevailed in the hospitals of the forward area, subperiosteal resections could rarely be performed, nor could the intensive care which is necessary in the after-treatment be given the individual case.

ANKLE

In wounds of the ankle, with considerable involvement of bone, astragalectomy is usually indicated, followed by complete closure of the joint. As Chutro [14] has emphasized, it is important to displace the foot backward after astragalectomy in order to provide a fulcrum of sufficient length, and to give proper weight-bearing lines. The ankle is one of the most troublesome joints to treat in the presence of infection. Suppuration often extends not only to the tarsal joints but also along the tendons of the foot, and amputation not infrequently results. Therefore a successful initial operation is especially important.

WOUNDS PRODUCED BY SHARP INSTRUMENTS

These should be treated on the principles outlined for wounds caused by projectiles. The soft parts should be thoroughly débrided; the joint widely opened, a wound of the bone or cartilage cleansed with chisel or curette, the joint irrigated, and the synovial membrane and capsule closed. The soft parts may be sutured or left open, according to the rules already laid down.

LATE COMPLICATIONS OF WOUNDS CAUSED BY PROJECTILES

In general, wounds of joints which have been properly treated progress satisfactorily if infection does not occur, and a large proportion of the patients regain full function in a relatively short time. On the other hand, the occurrence of infection seriously affects the outcome; not only is the mortality greatly increased, but even in the more favorable cases reestablishment of function is often prevented by partial or complete ankylosis. These two complications, infection and ankylosis, must be discussed in some detail.

SUPPURATIVE ARTHRITIS

Suppurative arthritis constitutes the most serious sequel to wounds of joints. As an early complication it has been considered under the postoperative treatment of recent wounds. Attention must now be directed mainly to the treatment of the later and persistent phases of joint suppuration which constitute one of the most difficult and discouraging problems of military surgery. A large number of these cases were treated in every base hospital of the American Expeditionary Forces. The most important factors which led to the development of chronic suppuration were ill-advised conservative measures rather than early operative treatment of the wound, failure of the initial operation to prevent infection, or ineffective early treatment of the infection itself. It should be stated, however, that in most cases failure of the initial operation was due to uncontrollable conditions, such as a long interval between

the receipt of the wound and the admission to the hospital, excessive and prolonged contamination, especially in association with bone lesions, or early evacuation with imperfect supervision of the patient and wound.

Every effort should be made to recognize the infection early in its development. If, after the initial operation or in cases in which no operation has been performed, the local examination or the general condition of the patient suggests infection, the joint should be aspirated. If the character or culture of the aspirated fluid indicates pyogenic infection, arthrotomy should be performed. In the case of staphylococci or streptococci there should be no delay; but where there is distention of a joint with turbid fluid, not containing pyogenic organisms, delay is warranted and aspiration may even be repeated. The injection of antiseptic solutions after evacuation of the effusion has met with some success.

No attempt will be made here to describe the appropriate incisions for the various joints and the details of dissection; such description may be found in standard works on surgery. One or more incisions should be made, unless an existing incision is so situated as to allow satisfactory drainage; in that event it should be reopened. Continuous drainage is best provided by Willems' method of active movements, especially in the knee joint (see infra). But if for any reason this method can not be carried out, for instance, by reason of extreme suffering, or considerable bone involvement, the Carrel-Dakin method of chemical disinfection is the best substitute. Moreover, in early cases of nonvirulent infection, especially with little bone involvement, success may rapidly follow the inauguration of this treatment. It is evident, however, that the construction of most joints renders it extremely uncertain whether irrigation of the entire joint cavity can be accomplished. Drainage by rubber tubes is objectionable in that the tubes produce pressure necrosis and do not drain adequately. They should never be used in superficial joints, as the elbow or knee. At times they must be employed in deep joints, such as the shoulder and hip. But it must be emphasized that any kind of drain within a joint is harmful and should be avoided if possible.

When cases have not been treated sufficiently early by arthrotomy and active movements or by the Carrel-Dakin method, or have failed to respond satisfactorily to these procedures, a chronic virulent infection may be expected. The articular cartilages and adjacent bone become involved and this renders joint suppuration long and serious. In general, a well-established suppurative process continues until the involved cartilage has been entirely eroded. Moreover, extension of the infection to the cancellous bone of the epiphyses, which quickly occurs if there are fissures or lines of fracture, leads to osteomyelitis, which is peculiarly resistant to treatment. In many cases the infection also extends to the soft parts, causing periarticular abscesses.

RESECTION

In cases which are not progressing satisfactorily under conservative methods resection offers a means of establishing satisfactory drainage, and is, in general, the best method of treatment. After resection the wound is treated

by the Carrel method. It may be allowed to close by granulation or, when sterile, may be closed by secondary suture.

Unfortunately, there is no single indication for resection in suppurative arthritis. It is this which makes decision so difficult and often too long deferred. Various factors must be weighed, such as the degree of local infection, the extent of bone involvement, the severity of septic symptoms, and the general resistance of the patient. The same factors must be considered in the decision as to whether resection or amputation should be done.

Amputation must be practised in a certain proportion of cases of prolonged joint infection, especially when there is such a degree of sepsis and diminished resistance that the less radical procedure of resection with the necessarily long after-treatment apparently can not be supported. Amputation is a life-saving measure where resection has failed or has been too long delayed, but nice judgment is necessary to determine when it is indicated. One is always averse to advise the sacrifice of a limb, and consequently many cases have been lost by persisting too long in more conservative measures.

The general treatment of septic joints having been outlined, certain specific details which bear upon individual joints must be considered.

The knee is the joint in which the most serious infections are encountered and is one of the joints most resistant to treatment. As Tuffier emphasizes, its anatomic structure alone will explain the frequent failure of irrigation and drainage. "Infection spreads backward sooner or later, and no amount of irrigation of the anterior cavity will affect suppuration in the posterior pouches." Frequently pus finds its way through the back of the joint into the deep portion of the popliteal space and then passes upward or downward along the great vessels and burrows among the muscles of the thigh and calf. Abscesses also may extend from the subcrural bursa anteriorly between the bundles of the quadriceps, especially between the rectus and vastus externus (Guénard).[15] Among 40 cases of suppuration of the knee joint seen by Guénard in the course of a year, such migratory abscesses were observed 14 times. Drainage of such abscesses by appropriate incisions is necessary; the occurrence of the abscess in itself does not, as a rule, demand more radical procedures. Of the various methods for drainage of the popliteal space, that advocated by Abbott is said to be very satisfactory. Through an incision on the inner aspect of the leg below the condyle the popliteus muscle is exposed and separated from the tibia. The space is thus drained with the muscle between the vessels and the drainage tract.

The knee is the ideal joint for the employment of Willems' method. Blake[16] states that functional results are obtained by this method which would be unattainable by any other treatment, and believes that this is due largely to the conservation of the cartilage and synovial membrane by the maintenance of function.

By reason of the gravity of wounds of the knee when complicated by infection radical measures are often indicated at a relatively early stage, the effort being made to control infection, though at the sacrifice of joint function. Therefore when cases have failed to respond satisfactorily to conservative

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treatment and the local and general conditions are bad and are becoming progressively worse, adequate drainage should be provided. For this, various methods have been practised, among which are: Transverse incision through the ligamentum patellæ; the patella is turned upward, the semilunar cartilages removed, and lateral and crucial ligaments divided, the knee is sharply flexed and held in this position until infection is controlled, when the joint is resected or, if possible, extended. Rankin [17] advocates a similar procedure, but opens the joint by means of a flattened inverted U-shaped incision through the quadriceps tendon which allows the patella to be turned down and gives free access to the subcrureus pouch. Chaput [18] and Guénard [15] advocate patellectomy. Fullerton [19] recommends resection with temporary wide separation of the ends of the bones. Ballance not only resects but removes the posterior margin of the sawn condyles in order that drainage of the posterior portion of the joint may be better ensured. In all of these methods the Carrel-Dakin treatment has been employed advantageously after adequate exposure has been obtained.

Drainage by resection has led to the best results. Not only is drainage thus established, but, in addition, the removal of the articular cartilages and much of the infected bone favors repair, since these tissues are largely responsible for the persistence of the infection.

As Fullerton [19] describes the operation, a U-shaped incision is employed, the patella is removed, and the articular ends sawn across, removing in all about two inches. A few stitches may be introduced in the middle of the flap, the remainder of the wound being left open. Wide separation of the ends of the bones is obtained by traction through a Thomas splint. The wound is treated by the Carrel-Dakin method. The ends of the bones are not allowed to approximate until infection is completely controlled, and then only gradually, the limb being immobilized in slight flexion. If union has not taken place when the wounds have healed, the case may be operated upon again and the freshened ends brought into apposition as in a clean case.

Resecting is indicated when the general condition permits, but in cases of long standing infection, with fever and poor general condition, amputation is sometimes advisable. In the lower limb its consequences are less serious than in the upper, and the results of delay are frequently disastrous.

For persistent suppuration of the shoulder, elbow, hip, and wrist, resection is also often indicated in cases which are doing badly. Details of resection, including subperiosteal resection, as well as the proper positions for ankylosis in these joints, are outlined elsewhere.

For persistent infection of the ankle, especially if there is an infected fracture of the astragalus, astragalectomy gives the best result.

Mobility Versus Stability After Resection

When adequate drainage has been secured by resection of a septic joint the choice between mobility and stability must be made. If stability is elected, the functional usefulness of the ankylosed joint depends almost entirely upon the angle of ankylosis. With special reference to the relative advantages of ankylosis in a favorable position or a certain amount of motion imperfectly controlled, Osgood [20] states "that with certain exceptions after septic com-

pound joint fractures, ankylosis in a position favorable for function is a result vastly superior to small degrees of fairly stable motion or large degrees of a more or less flail-like movement, always imperfectly controlled by muscle action. This is, without exception, true with respect to the shoulder joint, the hip joint, the knee joint, and the ankle joint, for people who must earn their livelihood. One exception is the elbow, which may in a few trades be better even flail than stiff, though it usually involves the wearing of apparatus. One other exception is the wrist, which, with a few degrees of motion, but never flail, may be more serviceable than a stiff joint. It will be noted that both elbow and wrist are nonweight-bearing joints, over which run certain tendons, all of whose attachments need not be disturbed by the excision. The muscular control of the joints may be to some extent thus conserved. Even these exceptions are debatable." These arguments seem sound and are sustained by such reports as Tavernier and Jalifier,[21] who describe numerous cases of flail joints upon which they operated to improve the function of the elbow, shoulder, and wrist. But most surgeons are not as definitely in favor of rigidity after resection of these joints. Their views are to some extent supported by the analysis of large series of cases, such as that of Tuffier. Osgood's recommendations as to the best angle of fixation for the different joints is given in a later paragraph.

Functional Results of Resection

Tuffier[8] has summarized the late results of joint resections. Based upon the examination of 1,810 cases, comprising: 630 elbows, 330 shoulders, 282 knees, 231 astragali, 152 wrists, 122 hips, 29 posterior tarsal joints, 14 anterior tarsal joints, he finds: Elbow, 49 per cent solid and with variable degree of mobility, 30 per cent flail, 20 per cent ankylosed. Shoulder, 45 per cent solid and with variable degree of mobility, 38 per cent flail, 16 per cent ankylosed. Wrist, 64 per cent solid and mobile to some extent, 36 per cent ankylosed. Hip, 30 per cent solid with restricted mobility; ankylosed, 48 per cent. Ankle (astragalectomy), 20 per cent solid with some mobility; ankylosed 70 per cent. In the knee the operation does not aim at mobility, but rigidity. Ankyloses occurred in 85 per cent of the cases.

Resection of a joint may be indicated at the primary operation when there is such destruction of the articular surfaces as to preclude saving the joint, or secondarily for severe suppuration to obtain adequate drainage, or remotely, in order to give greater mobility or greater strength to the limb. The cases analyzed by Tuffier were all of the first and second of these three groups.

ACTIVE MOBILIZATION IN PURULENT ARTHRITIS—WILLEMS' METHOD

In applying mobilization in the treatment of purulent arthritis Willems'[6] original purpose was to secure efficient drainage after arthrotomy. He found that there was no system of irrigation which could be depended upon to limit the extension of the infection, not even the Carrel procedure, and that resection solely to ensure drainage appeared too radical. He therefore endeavored to drain the joint by squeezing out the pus through active movements. His early attempts were convincing. He states that when an infected joint has

been opened by unilateral or bilateral arthrotomy the patient can move the joint without difficulty. With each movement of flexion and extension pus is expelled. This expulsion is the more complete the more extensive the movements and the more vigorous the muscular contractions. When these movements are repeated a sufficient number of times all the secretions are expelled. The suppuration usually lasts for weeks, first profusely, then diminishes to a few drops daily, and finally ceases. For a long time a fistula persists which closes periodically and must be reopened in order to drain the small quantity of retained secretion. The swelling of the periarticular tissues persists to some extent until after complete cicatrization. Periarticular abscesses are practically unknown. The general condition improves very rapidly. Active mobilization thus accomplishes ideal drainage without the assistance of any other measures.

The movements become easier and less painful the oftener they are repeated. The muscles are very slightly affected by the arthritis. The quadriceps and the brachial biceps, which usually undergo rapid atrophy in purulent arthritis of the knee and elbow, remain surprisingly strong. The end of the treatment is usually reached with an almost negligible degree of atrophy.

As soon as the articulation becomes dry, a tendency to stiffening is occasionally noted. In order to avoid this danger, Willems partially closes the arthrotomy wounds when the suppuration has become markedly diminished, only a small opening being left corresponding to that portion of the wound where the secretion still persists. By this method the mobility can almost invariably be preserved, at least to a great extent; not infrequently it is perfect. Willems attributes the satisfactory results to limitation of the infection to the synovia as the result of perfect drainage, which militates against its extension to the cartilage and bone.

He admits that all articulations are not equally well adapted to drainage by arthrotomy and active mobilization. The thoroughness of the drainage is proportionate to the more or less extensive range of movements of the joint. From this viewpoint the elbow and the knee, which can perform wide excursions, are the most favorable. The wrist and ankle, where extension and flexion are more limited, expel the secretions less thoroughly, and in these joints the method has yielded less rapid and less complete results.

Willems reports 20 cases of suppuration of the knee, with no deaths, no amputation, 1 resection, 3 cases of ankylosis. The functional results were, in general, good and in many cases perfect.

Willems' technique is as follows:[6] In the cases of serous staphylococcus synovitis it is sufficient to reopen the original incision. In the presence of streptococcus infection classical bilateral arthrotomy is indispensable. The joint must be opened very widely on both sides. The wounds are covered with aseptic dressings loosely applied. No immobilizing appliance is employed. Hot dressings are applied for the first 48 to 72 hours, changed every 2 to 3 hours if considerable joint swelling and local reaction follow the operation.

As soon as the patient wakes he is instructed to begin active movements. His confidence must first be won by having him carry out with the healthy limb the movements which he is to do with the wounded limb. In

the cases of the knee the procedure is as follows: First the patient raises the entire limb from the bed; he flexes the thigh on the pelvis, then alternately flexes and extends the leg on the thigh. Delrez considers it a noteworthy fact that although passive movements are extremely painful, active movements cause no inconvenience, the patient complaining of heaviness of the limb, but not of pain. The first sessions are fatiguing, later ones becoming progressively easier. The active mobilization must be repeated at least every hour during the day and two or three times in the course of the night. The patient is gotten out of bed as soon as possible, using his injured arm or leg if the temperature is low and bone lesions do not contraindicate. Cases in Delrez's service were seen walking about with pus escaping from the knee joint at every step. It was observed that some patients had to be urged and almost driven to use the limb. If this was done early, little pain resulted; if delayed or used only after a long interval, motion was painful and restricted. Cessation of movements was usually followed by accumulation within the joint, associated with increased pain and temperature reactions. The method undoubtedly affords a valuable weapon of defense against suppurative arthritis.

ANKYLOSIS

The treatment of deformities with impairment of function resulting from partial or complete ankylosis has been outlined by Osgood [23] in an admirable article which is here summarized: If the joint has been the seat of a serious infection, it is usually unsafe to undertake considerable operative procedures for from six months to a year after the subsidence of the sepsis. Judgment as to when these surgical attempts are safe is always difficult. Massage more or less violent may serve as a guide. If, after such massage, a definite recrudescence of the cardinal signs of inflammation occur, it is usually unsafe. The absence of this reaction is suggestive of sufficient quiescence to make operation possible.

The first determination is whether mobility or ankylosis in a favorable position for function is to be sought. It must be recognized, however, that restoration of perfect mobile function is rarely possible in these cases. Only the hip and the elbow should be attempted, the hip more rarely than the elbow.

The great majority of the cases in which decision between attempts at mobility or ankylosis in a favorable position must be made occur in war surgery among workingmen whose wage-earning capacity must be the controlling factor in this decision. It is a matter of constant surprise to find how little disturbance of wage-earning capacity is caused by a completely stiff joint in a favorable position for his trade. Generally speaking, the shoulder should be fixed in 50° to 80° abduction, in a plane about midway between the anteroposterior and lateral planes of the trunk; that is, the elbow should come somewhat forward. A single elbow should be fixed in such position that the angle which the forearm and upper arm inclose is about 100°; that is, a little more obtuse than a right angle. Where both elbows are ankylosed, one should be a little more than a right angle (100° to 110°), the other a little less than a right angle (70° to 80°). In both these positions the hand should be midway between pronation and supination. The wrist should be in dorsal flexion. The hip should be fixed in 5° to 10° abduction, 5° to 10° outward rotation, and 10° to 20° of flexion. The

knee should be fixed with varying degrees of flexion up to 45°, depending on the occupation. The ankle gives best function in right-angle dorsal flexion, with perhaps a little equinus to allow for the heel of the shoe. We are inclined to believe that in the vast majority of cases, except possibly the elbow joint, ankylosis in a favorable position should be the operation of choice in war surgery in case of terminal joint deformity.

Partially Ankylosed Joints With or Without Deformity

The problem with partially ankylosed joints, according to Osgood,[23] is the restoration of as large a range of mobility as possible. "In joints which have been the seat of an infection," he says, "gentleness of manipulation is the rule to be followed almost without exception. Brisement force under an anesthetic is rarely successful in gaining greater range of motion and is often provocative of a lighting up of the old infection. It is to be thoroughly discouraged. Light massage, mechanotherapy, and hydrotherapy are the first procedures, accompanied by gentle passive movements and the stimulation of the patient to carry out active movements. These latter are by far the most important. Between these treatments, apparatus is often of great advantage, both that which retains motion gained in the direction desired and that which by elastic pull constantly exerts gentle traction in the appropriate lines. Recovery is gradual and often seems to the patient slow and tedious. If his endeavor to gain motion is coupled with the stimulation of a definite occupation, which accomplishes a purpose of some sort, time passes more quickly, motion increases automatically and almost unconsciously. Tailoring, carpentry, leather working, brace making, printing, basket making, and farming are all easily adapted occupations."

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CHAPTER XIV

WOUNDS OF THE CHEST

At the time the United States declared war on Germany, effective methods for treating various types of wounds, with some few exceptions, had been established by surgeons of the Allied armies. Among these exceptions were wounds of the chest. There were wide and some irreconcilable differences of opinion as to the care of intrathoracic injuries. These differences were caused by failure to understand the interdependence of the functions of the circulatory and respiratory apparatuses and to appreciate the contribution of their functions to the powers of resistance, defense, and repair, powers which must be conserved and developed in order to facilitate immediate recovery and to minimize the extent and duration of subsequent disability.

The possibilities for rendering service to the wounded in this direction, as well as in others, through investigations of inherent problems were recognized early in the history of the American Expeditionary Forces by the then chief of the research division of the American Red Cross in France. He secured early opportunities to begin these studies, and, in so far as he was permitted, continued to give assistance; special apparatus was provided for experiments; also supplies of oxygen and nitrous oxide gases, and transportation, which were essential and otherwise unobtainable, were provided.[1]

Work was begun by the writer in 1917 at the Ambulance de l'Ocean, at La Panne, Belgium, under Col. A. Depage of the Belgian Medical Department, and included clinical, post-mortem, and experimental observations. This work sufficed to disclose the more significant problems and to indicate means for their solution.

Late in 1917, the chief consultant, surgical services, of the American Expeditionary Forces, recommended continuation of the work, and in 1918, the chief surgeon, A. E. F., detailed for this purpose medical officers, nurses and enlisted men for duty at the Central Medical Department Laboratory at Dijon.[2]

Experimental studies, carried on in the section provided for surgical research, with the help and advice of the director and of the chief of the division of surgical research, were continued until the Chateau-Thierry operation began.

After this time, and until the beginning of the armistice, a unit [a] composed of medical officers, nurses and enlisted men appointed by the chief surgeon, A. E. F., was detailed to sundry field hospitals for the care of nontransportable wounded and to mobile hospitals in zones where there was active fighting.

The directions of the chief consultant of the surgical services were (1) to discover the physiologic interrelationships between the circulatory and respiratory mechanisms in order to determine the functions which need the protection

[a] The members of the unit detailed to the study and treatment of thoracic injuries were: Col. J. L. Yates, M. C., in charge; Maj. W. F. Verdi, M. C., surgeon; Capt. W. S. Middleton, M. C., and Capt. M. A. Blankenhorn, M. C., physicians; Capt. Robert Drane, M. C., and Capt. J. M. Steiner, M. C., radiologists; Capt. J. T. Gwathmey, M. C., and Anna Fitzgerald, A. N. C., anesthetists; Anne Bernard, A. N. C., surgical nurse.

to assure the largest opportunities for immediate and remote recoveries; (2) to develop the simplest effective surgical methods compatible with physiologic requirements; (3) to apply these methods to the wounded whenever there was any possibility of saving life and without regard to the high mortality rate that would inevitably accompany acceptance of the gravest risks; (4) to follow each fatality with necropsy to determine what should not be done, to trace the results in those who recovered and thereby discover the dependence of degrees of functional rehabilitation upon methods employed in order to get better methods; and (5) to make eventually a report indicating how soldiers suffering from intrathoracic injuries could be the more certainly protected against death and disability.

What follows in this chapter is in consequence of compliance with these directions. No attempt has been made to preserve chronologic sequence in observations; facts as they now appear important are presented. Statistics are avoided as far as possible since, because of the many inevitable sources of error, they can not fail to be even more than usually unreliable.

PHYSIOLOGIC INTERDEPENDENCE OF RESPIRATION AND CIRCULATION

Two factors, peculiar to thoracic injuries, are of sufficient importance to be kept constantly in mind: First, mere existence, as well as additional activities, including the capability of withstanding the extraordinary stresses imposed by wounds and by surgical treatment, depends fundamentally upon ability to provide oxygen for tissue metabolism. Second, chest injuries impose not only the burdens incidental to other tissue insults but also definite restrictions to the supply and delivery of oxygen.

Suitable methods of treatment will protect the means whereby oxygen is supplied to the body and delivered throughout the body and will be determined by knowledge of the activities upon which the functions of supply and delivery of oxygen depend. A summation of all relevant observations made by the writer during and since the World War was presented before The American Association for Thoracic Surgery in 1924.[3] It is given here in full, with a few minor changes, as it indicates the essential activities and functions, and how they may be conserved and rehabilitated.

THE SIGNIFICANCE OF VITAL CAPACITY IN INTRATHORACIC THERAPY

A biologic aphorism, no life without breathing, indicates in a general way the importance of respiration. Activities sufficient merely to support life or to realize the utmost physical and mental powers, including defense and repair, are produced by metabolic processes which are dependent primarily on oxidation. This explains why man, although he may survive for weeks without food and for days without water, can exist for only a few minutes deprived of air. It also explains why any reduction in supplies of oxygen to the body, in deliveries of oxygen throughout the body and in utilization of oxygen by the body, imposes a corresponding degree of disability.

The many diseases affecting the thorax and its contents, the enormous totals of transient and permanent disabilities and the large number of deaths

they cause constitute a serious problem. More effective therapy is needed to provide greater limitations of disability and to reduce mortality.

There is a direct road to this accomplishment. Reduction in vital capacity is so constant a result of thoracic diseases that the extent of this reduction is an accurate measure of the disabilities attributable to them.[b] In order to obtain better methods of treatment, it is essential to know the structures and the functions of the structures that determine vital capacity, how vital capacity is affected by various lesions and consequent malfunctions of these structures, and how therapeutic methods can protect vital capacity against reduction during aggressive phases of diseases and facilitate its rehabilitation during regressive phases.

Four distinct phases are notable in completed respiration: (1) Ventilation of intrapulmonary air effected by breathing; (2) external respiration, the interchange of gases between the intrapulmonary air and intravascular blood through alveolar and capillary walls; (3) transportation of aerated blood to somatic cells and of blood needing aeration to lungs by a coordination of the pulmonary and systemic circulations, and (4) interchange of gases between blood and tissues through capillary walls and cell surfaces, or internal respiration. Although most essential, internal respiration is germane to this subject only as it is influenced by the other steps in complete respiration.

Clinical interest centers in the finer workings of the mechanisms of breathing, of circulation, and particularly of external respiration, because of its direct relationships to vital capacity and to life itself. External respiration not only accomplishes aeration of blood throughout life, no matter how great or how little are the demands for oxygen, but this accomplishment has to be relatively complete at any or all intervals. In order to simplify the immediate presentation, let it be supposed that the walls of all of the alveoli are fused into one sheet of epithelium against which is applied a similar sheet composed of the pulmonary capillary endothelium. Suppose further that the intrapulmonary air is in an even layer on the epithelial surface and the intrapulmonary blood is flowing in another even layer on the endothelial surface.

Conditions being normal, the oxygen in the layer of air suffices to aerate homogeneously and completely the layer of blood as it passes over the endothelial surface. Should the amount of blood be increased, either the area of the sheet of endothelium must be enlarged or the layer of blood must become thicker. If the layer of blood becomes too thick, it will be aerated neither homogeneously nor completely. On the other side, if the intrapulmonary air be in too thick a layer, because the area of epithelium is too limited, aeration is likewise defective. The states of defective aeration, anoxemia and cyanosis, are abnormal. Therefore, it is presumable that there is a natural control which correlates the volume of ventilated air and the area of alveolar epithelium

[b] Estimations of vital capacity are not always the only or even the most dependable sources of information. Frequently, it is impracticable to make them. Occasionally, they can lead to erroneous interpretations. As will be made clear later, vital capacity is influenced by the circulation. An individual may have an apparently competent circulation while at rest and show at such times an approximately normal vital capacity; yet that same individual, if the reserve cardiac energy were limited, would show a material reduction in vital capacity after exercise which would be less of a tax on the myocardium than many types of diseases or operations. Other examples need not be cited. This suffices to emphasize the fact that vital capacity readings, like other single sources of clinical information, are reliable when intelligently interpreted in conjunction with all other evidence.

(degree of inflation) with the expanse of endothelium (cross section and length of capillaries) and the amount of blood (unit volume). Moreover, since the demand for oxygen comes from the tissues and is manifested by increments of carbon dioxide in the blood, it is likely that the unit volume of blood in the pulmonary capillaries exerts a telling influence on the three other variables.

A further step in presenting the problem is a supposition that the sheet of alveolar epithelium has been turned into a single sac communicating with a bronchus, and the layer of blood is confined in loops of contiguous capillaries connected with the pulmonary artery and vein. Conditions affecting each of the many alveoli which constitute the portion of the breathing unit directly concerned in external respiration would then be illustrated by a single large alveolus.

Obviously, the first and great commandment is to discover the means whereby the amount of blood requiring aeration establishes conditions suited to this accomplishment.

Knowledge of the structures constituting the apparatuses of breathing and of circulation can alone determine therapeutic priciples. It is necessary to know how they operate during periods of rest; what adjustments occur when activities are gradually or abruptly increased and diminished; what adaptations are employed to meet handicaps imposed by disease; what are nature's methods to increase resistance and to hasten repair; what forms of treatment cooperating with natural methods of adjustment, compensation, and adaptation will augment defense most effectively and facilitate functional recovery.

Breathing, external respiration, and the deliveries of blood to and from the lungs are effected by extrathoracic and intrathoracic structures which are so intimately associated physically or physiologically, or both, that they must be considered together.

The extrathoracic portions need not be described in detail. It is only necessary to recognize that the chief control of the distribution of blood in the systemic circulation and the rate of flow in both systemic and pulmonary circuits, as well as the rate and depth of breathing efforts, is in the central nervous system.

The intrathoracic portions not only provide external respiration but they also are the structures affected by the diseases here considered, and give diagnostic, prognostic, and therapeutic indications.

An accurate measure of the efficacy of external respiration is vital capacity, which is usually defined as the amount of air expelled by the most complete expiration after fullest inspiration. This means that when the air cells are distended to physiologic limits, inflation, and therefore the total area of alveolar walls, are greatest for normal conditions and are thus disposed to aerate equivalent amounts of blood.

Aeration is an exchange of oxygen and carbon dioxide through alveolar and capillary walls. Natural economy has apparently established a means of control whereby the total expanse of alveolar wall as determined by the extent of pulmonary inflation compels corresponding variations in the total expanse of capillary wall and the amounts of intracapillary blood. Grades of pulmonary

inflation are actively determined by variations in rate, depth, and force of breathing movements, and, as will appear later, are influenced passively by the unit volumes of blood in the pulmonary capillaries. Length, diameter, and, therefore, the contents of pulmonary capillaries can be attributed to three forces, since there is no effective vasomotor control of the pulmonary circulation. These forces are the blood pressures in the pulmonary circulation, fluctuations in intrapleural negative pressures, and alternating intravascular aspiration and expression caused by elongation and shortening of blood vessels with the inspiration and expiration of each breathing cycle.

In addition to central control by the nervous system, there is a peripheral intrathoracic governor which so coordinates the activities of the breathing and circulatory units as to keep volumes of ventilated air present in the alveoli which will aerate at any and all times those amounts of blood being driven through the capillaries. The governor simultaneously correlates the other two factors, namely, the total area of alveolar epithelium and the entire expanse of capillary endothelium.

Knowledge of the structure and function of the governor or gear which coordinates the two sets of variables, volumes of ventilated air and area of alveolar epithelium, with expanse of capillary endothelium and amounts of blood to be aerated, is of basic importance, since it determines how external respiration is affected by disease and can be benefited by treatment.

Moreover, such knowledge answers two other significant questions: Why are reductions in vital capacity so accurate a measure of disabilities? What are the structures and what are their activities that influence vital capacity?

Investigation of the various actions and reactions exhibited by the units concerned in respiration during health and the changes imposed by diseases should answer the question. It is necessary to observe the changes in those units under various conditions.

Normal respiration is possible so long as movements of thoracic parietes, particularly of the diaphragm, are unrestricted; intrapleural negative pressures are undisturbed, and pulmonary elasticity is not impaired, provided the right heart delivers adequate amounts of good blood in the absence of obstruction due to incompetence of the left heart.

NORMAL RESPIRATION DURING REST

During periods of rest, expenditures of energy and hence demands for oxygen are least. In consequence, the volume of tidal air, that exchanged with each complete breathing cycle, is lowest, as is the tidal blood, the amount driven through the pulmonary capillaries during the same breathing cycle. Aeration of tidal blood of rest is accomplished by the tidal air of rest which produces the lowest level of pulmonary inflation with minimal expenditures of energy. This is the period of greatest physiologic economy in which the storage of energies exceeds expenditures by the largest margin.

The reserve supply of air stored in lungs during periods of rest is five or six times larger than the tidal air. Approximately three-fifths of the reserve air is available for sudden physiologic requirements, leaving two-fifths to meet

urgent pathologic demands. A comparable amount of reserve blood available for similar emergencies is stored, less actively circulating, in larger pulmonary vessels.

Tidal air, approximately three-eighteenths of all the air concerned in breathing, serves to ventilate the intrapulmonary air more than enough to keep its oxygen content effectively high. Although one-third of the tidal air is required to fill the trachea and bronchi, the remaining two-thirds causes a change estimated at three-twentieths in the sizes of the air cells.

Thus there is an established relationship between the volume of tidal air (three-eighteenths) and variation in sizes of air cells (three-twentieths). Presumably the same relationship obtains between the amount of tidal blood and the length and cross section of capillaries. All combine to afford the means to aeration of the blood circulating through the pulmonary capillaries.

NORMAL RESPIRATION—ACTIVITIES GRADUALLY VARIED

As activities gradually are increased after a period of rest, the slowly progressing demands for oxygen are met by proportionately higher levels of inflation produced by larger volumes of tidal air and by increased amounts of tidal blood driven by higher pressures.

Relationships between tidal air and alveolar size and between tidal blood and capillary dimensions occurring during rest are but little distorted though produced less and less economically as activities increase.

A level is reached which may be termed optimum, whereat the tidal air equals the vital capacity. This is the upper limit of economic expenditures of energy at which extraordinary activities can be prolonged without causing early exhaustion. When this level is unusually high, it gives the remarkable endurance exhibited by exceptional athletes, by superior race horses, and by certain individuals in meeting the stresses of disease.

Activities raised above the optimum level initiate compensatory responses and mark uneconomic expenditures of energies which assure exhaustion. In order to supply the oxygen demanded for internal respiration, breathing is more rapid and the heart beats faster to develop higher pressures. Finally a still higher level is reached which may be called maximum, because at this level the utmost powers are realized for the brief period before exhaustion forces reduction in activity.

When the sequence is reversed, the processes are orderly reductions in breathing and cardiac rates and diminutions in volume of tidal air, pulmonary inflation, the amounts of tidal blood and capillary expanse. The relationships between the total areas of alveolar walls and capillary walls are adapted to the blood that requires aeration and the intrapulmonary air, properly ventilated, which supplies the oxygen.

Gradually increased activities provide opportunities for orderly adjustments in the actions of respiratory units and develop the largest total power of which an individual may be possessed. Hence the desirability of a suitable warming-up process before severe contests.

NORMAL RESPIRATION—ACTIVITIES VARIED ABRUPTLY

If a resting individual should suddenly engage in a critical physical contest, the demands for oxygen would jump in a few seconds from lowest to highest limits. The reserves of air and of blood stored in the lungs would be utilized until compensation could be accomplished. It has been estimated that the amount of blood delivered by the pulmonary circulation can be increased abruptly more than tenfold. Or should the individual while driving at the maximum level of action suddenly change to complete rest, the rate of external respiration measured by deliveries of aerated blood would decrease with almost the same rapidity.

The relationships between volume of air and total area of air-cell wall and amount of blood and expanse of capillary wall must be preserved with a fair degree of accuracy not merely to effect proper aeration of blood but to continue life. A very few seconds suffice to cause dilatation of the right heart or to produce edema of the lungs. These complications are seen infrequently because of a peripheral means of control that maintains the air-cell-capillary balance.

Abrupt changes are not alone less economic than are gradual but also are more dangerous, as they permit less opportunity for orderly adjustments and are operated almost entirely by expenditures of reserve energies or margins of safety.

This also applies to the handicaps imposed by disease. The more gradually induced are the less immediately dangerous, and this principle should be recognized in methods of treatment. Changes affecting the relationships involved in aeration of blood should be minimized in extent and in the rapidity with which they are produced.

ADAPTATIONS TO PATHOLOGIC STATES

Vital capacity is a suitable term. It does not occur post mortem. When it is less than the tidal air of rest, life can not continue. If it is equal to the tidal air of rest, existence is possible until the relationships effecting external respiration are disturbed by increased demands for oxygen. The excess of vital capacity over the tidal air of rest measures ability to work and the margin of safety.

Observations of natural adaptations to the handicaps of diseased states are as valuable as they disclose the compensatory changes that assure the nearest approach to normal external respiration of which the measure is vital capacity.

Normally, a volume of ventilated air on one side of a sheet of alveolar epithelium of exactly proportionate dimensions is separated by the interposition of another wall of vascular endothelium just as exactly proportionate in area to an equivalent amount of blood needing aeration. Normally, these variables fluctuate synchronously and almost equally. The upper limits are set by the total areas of epithelium and endothelium which can be presented, since the volume of air and blood can be further increased by raising the respiratory and cardiac rates for brief periods.

Limitations in any of the four factors—volume of ventilated air, total expanse of alveolar epithelium, total area of vascular endothelium or unit

volume of good blood—reduce the essential function, external respiration, which is manifested by corresponding reductions in vital capacity.

Adaptations strive to maintain the broadest margin of safety or the largest vital capacity. When a part of the alveolar epithelium is incapacitated, the remaining portions are expanded so that the total area available for external respiration may remain as nearly normal as possible. This is compensatory or physiologic emphysema. Likewise, the unit volume of blood is correspondingly increased in the capillaries in contact with hyperfunctioning alveoli. This is compensatory or physiologic hyperemia. Moreover, the unit volume of blood is reduced in the capillaries adjacent to the incapacitated alveoli. Similarly, increase or decrease in the unit volume of blood delivered through capillaries is associated with equivalent inflation or deflation of corresponding alveoli. Passive congestion is quite different. The capillaries are engorged, but the unit volume of blood passing through them is reduced. Pulmonary elasticity is restricted, and the total area of alveolar epithelial surface is diminished. Reduced vital capacity here also indicates the limitations in external respiration.

The important connection in maintaining the relationships which determine external respiration lies between the air cells and the capillaries. The interdependence of alveolar inflation and volume of air on one side and of capillary size and amount of blood on the other side is obvious.

Air cells and capillaries are not only intimately associated functionally but closely related physically. Capillary loops, arranged in a meshwork, surround, separate, and yet connect alveoli. When inflation increases, capillaries are straightened and elongated; when it decreases, they are shorter and more tortuous; hence, the aspiration and expulsion of blood with inspiration and expiration. Contrariwise, if tortuous capillaries are straightened and elongated by increased unit volumes of blood, the walls of corresponding air cells are carried with them and inflation results. Also, if this action, which corresponds to a positive phase in erectile tissue, is reversed, capillary walls are less tense, vessels shorten, and their lumens are decreased, air cells contract, and some deflation occurs.

This is the peripheral control, the intrapulmonary governor, and may be called the air cell-capillary gear.

The existence and functions of an air cell-capillary gear are not generally recognized and are disputed by clinicians as well as by physiologists.[c] The

[c] Haldane remarked the need of a governor: "We have no guaranty that even during quite normal breathing the distribution of air in the individual lung alveoli corresponds exactly with the distribution of blood to them. Unless this correspondence is exact some alveoli will receive more air in proportion to their blood supply than others, and, as a consequence, the mixed arterial blood will be a mixture of more or less fully arterialized (aerated) blood with some of the consequences first discovered (anoxemia). It is probable indeed that in some way or other the air supply is proportioned to the blood supply whether by regulation through the muscular coats of the bronchioles or regulation of the blood distribution; but it is also certain that this proportioning is only an approximation" (Haldane J. S.: Respiration, Yale University Press, New Haven, Conn., 1922, 137).

Certain it is that all the alveoli are unequally supplied with air. Fluoroscopic observations of normal breathing prove this in the increased inflation of the zone of lung adjacent to the diaphragm during each inspiration. The control of air and blood, as suggested by Haldane, would scarcely afford an approximation in the proportioning. On the other hand, the air cell-capillary gear provides exact proportioning for each alveolus though not the same proportioning for all alveoli, else there could be no compensation in health nor adaption in disease. Inequalities in alveolar inflation and in the ventilation of intra-alveolar air would occur even in health, and could explain the mixtures of more or lessperfectly aerated blood noted by Haldane.

latter demand properly controlled crucial animal experiments for proof that would be acceptable to them. They are unaware that one animal, even though denied the distinction of being included among laboratory species, has been giving conclusive although spontaneous demonstrations for centuries. Clinicians have recognized, in those demonstrations, the signs and symptoms of natural adaptations to intrathoracic diseases which occur in man.

Animals are divisible, as Miller[4] showed, into those having thin pleuræ and those having thick pleuræ. Animals with thick pleuræ have mediastina which are impervious to air and to water. The blood supplied to lung parenchyma and visceral pleura comes chiefly from the bronchial artery. Animals with thin pleuræ have mediastina which are pervious to air and to water. Their lung parenchyma and visceral pleura obtain blood supply more largely from the pulmonary artery. Man is of the thick pleura type. Observations made on the usual laboratory animals (cat, dog, and rabbit), which are of the thin pleura type, are not directly applicable to man. Attempts to use such experimental observations directly in explanation of human physiologic and pathologic manifestations have led to confusions which are the bases of most misconceptions.

The evidence for an air cell-capillary gear is direct and indirect.

If the pulmonary artery is ligated or obstructed in man or in other animals with a thick pleura, the portion of the lung supplied is deprived of function. It atrophies, contracts and becomes airless. There is no infarction. If a bronchus is ligated or obstructed and pneumonia is not occasioned, the portion of lung supplied is deprived of function. It atrophies, contracts and becomes airless. There is no infarction.

In man, no portion of lung which has had either its air or pulmonary arterial supply destroyed can be functionally rehabilitated. Obviously, if either part of the air cell-capillary gear is incapacitated, the other part is simultaneously disabled.

If the rate and depth of respiration be increased above normal, the carbon dioxide content of the blood is reduced and apnea results. The unit volumes of blood in the pulmonary capillaries are increased because inflation is increased. Extraordinary aeration results, not because of tissue demands expressed through central nervous system control, but because of the coordinating action in breathing and circulatory units effected through the peripheral governor.

If the rate of cardiac contractions is suddenly increased by emotions, there is a correspondingly increased inflation; respirations are deeper and more rapid. There is a transient sense of air hunger. This is a common experience. Inspirations are involuntarily deeper because a larger unit volume of blood is delivered through pulmonary capillaries at higher pressures and inflation of alveoli is inevitable.

Animal experiments are thus far unsatisfactory. Negative-pressure cabinets are required to eliminate complicating factors incidental to disturbed intrapleural negative pressures and to the intratracheal positive pressure usually employed. Pneumothorax or hydrothorax induced in an animal with a thick pleura causes a contralateral compensatory emphysema proportionate to the amount of air or water introduced. The animal will tolerate increasing

positive pressures so long as it is able to develop and to maintain the higher pulmonary arterial pressures required to develop the degree of contralateral compensatory emphysema required for external respiration. If the animal be fatigued previous to the experiment, the limit of tolerance is lowered because cardiac energies are less. If the same experiments are made on animals with a thin pleura, pneumothorax and hydrothorax are soon bilateral; compensation is less possible because intrapleural pressures of both chest cavities vary together and toleration is limited. Further confirmation lies in the fact that as animals with a thick pleura are progressively exhausted, the tolerance of intrapleural positive pressures falls until it equals the intolerance of animals with a thin pleura.

Observations have been made often enough during operations on human beings to furnish sufficiently reliable controls to satisfy all requirements for accuracy. The following examples are pertinent. When chronic pleuritic adhesions are divided before pulmonary elasticity has been permanently destroyed, the underlying lung, relieved of restraint, bulges outward if the patient is in fairly good shape even when no differential pressures are employed. If, during an open thoracotomy performed on a strong patient under positive pressure anesthesia, the positive pressures are reduced or stopped, the mediastinum bulges toward the open side. A focal parenchymatous hemorrhage is surrounded by a halo of emphysema. The focal pressure of a finger on visceral pleura will produce emphysema in the adjacent lung.

Other observations, after lobectomies, are notable. Each lobectomy causes greater compensatory emphysema in the remaining lung. The limit of lung capable of supporting life is that which will provide a vital capacity slightly in excess of the tidal air of rest.

Attempts to observe actions of the air cell-capillary gear in excised lungs are quite futile. Post-mortem changes occur rapidly. Blood pressures in the bronchial artery are absent. It is impossible to wash out all the blood from the capillaries. The effects of negative pressures are lost. The amount of force which must be applied to drive water through the pulmonary arteries exceeds the strength of the capillary endothelium and alveolar epithelium. Leakage through the air passage results. Inflation of lung by forcing air into bronchi will not cause the pulmonary artery to aspirate fluid because the capillaries are plugged or collapsed. Injecting water into the pulmonary veins causes no inflation just as might be expected because passive congestion is known to reduce vital capacity.

On the other hand, sufficient air pressure in the pulmonary artery will cause inflation of the lung and aspiration of fluid by the bronchus before the capillary walls are ruptured.

The simplest experimental demonstration is to ligate with suitable precautions in a strong living animal the pulmonary artery of one lung and to observe by Röntgen-ray examination the increased compensatory emphysema produced in the contralateral lung.

All the manifestations noted can be explained by the interactions of pulmonary inflation and deflation and of the amounts and pressures of blood in

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pulmonary capillaries effected through the air cell-capillary gear. They are supplemented by the forces of blood in the bronchial arteries which fluctuate with physiologic activities of the lung, since they are under control of the systemic vasomotor mechanism.

Dunham had recognized the air cell-capillary governor and constructed a model to illustrate its actions as shown in Figure 180. The jar represents a pleural cavity. It contains a rubber bag, an air cell instead of a lung, connected with the middle glass tube instead of a bronchus. The glass tube at the left is connected with a coil of guinea pig's intestine glued to the air cell to imitate a pulmonary capillary. The tube at the right makes it possible to establish negative or positive (intrapleural) pressures. Suitable variations of air pressures exerted through the three tubes demonstrate the effects of breathing, fluctuations in unit volumes of blood delivered to the pulmonary capillaries, and changes in intrapleural pressures. The model has been criticized because the pulmonary capillaries have been represented as end vessels. A moment's consideration will explain how difficult or impossible it would have been to reproduce a complete circulation and how unnecessary. Whether or not some blood passes through the capillaries, a sufficient unit volume of blood would cause them to straighten and to elongate.

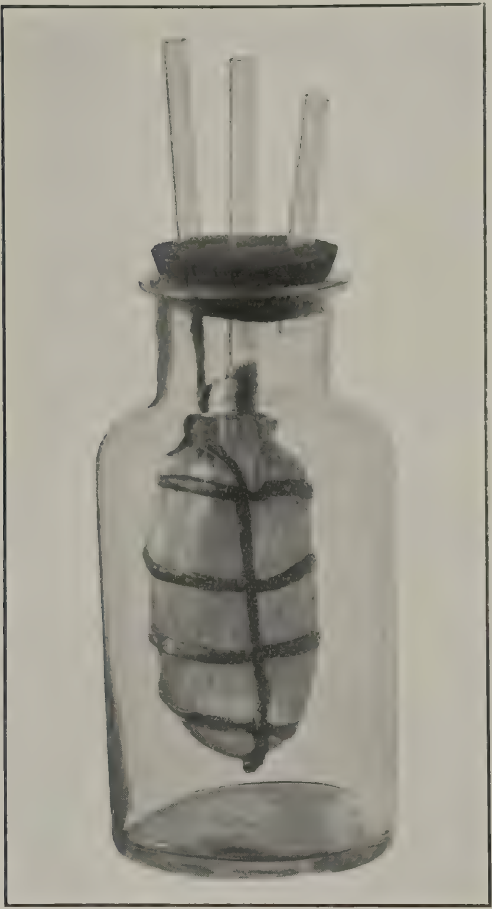

FIG. 180.—Dunham's original model of the air cell-capillary gear

The adaptations are few in number. Their effectiveness varies directly with grades of competence or incompetence of the circulatory unit. Hence, there are many variations in extent though none in character of responses.

COLLAPSE

Collapse results when intrapleural negative pressures are neutralized by an open thorax or intrapleural exudates of appropriate amounts. One or both lungs may be affected. The extent of collapse is determined by elastic recoil of the lung opposed by the expansive forces exerted through the pulmonary and bronchial arteries. The lower the blood pressures, the greater the collapse. The greater the collapse, the less reserve air and blood in the lung, the less the residual air is ventilated, the less blood is in circulation and the more urgent the

need for contralateral compensation to protect external respiration. Unfortunately, the greater the need, the less the capacity to develop compensation.

Another important influence is the rapidity of reductions in negative pressures. As already noted, adjustments are most effective when they are induced gradually and thus occasion less unfavorable expenditures of energies.

Observations on the effect of war injuries and surgical wounds of the thorax have proved that a competent individual can survive a wide parietal opening even when suddenly produced, whereas a comparable individual, made incompetent by exhaustion, exposure, starvation, hemorrhage, dehydration, and infection can barely tolerate a small opening. Likewise, it has long been known that a gradually increasing pleuritic exudate is of far less moment

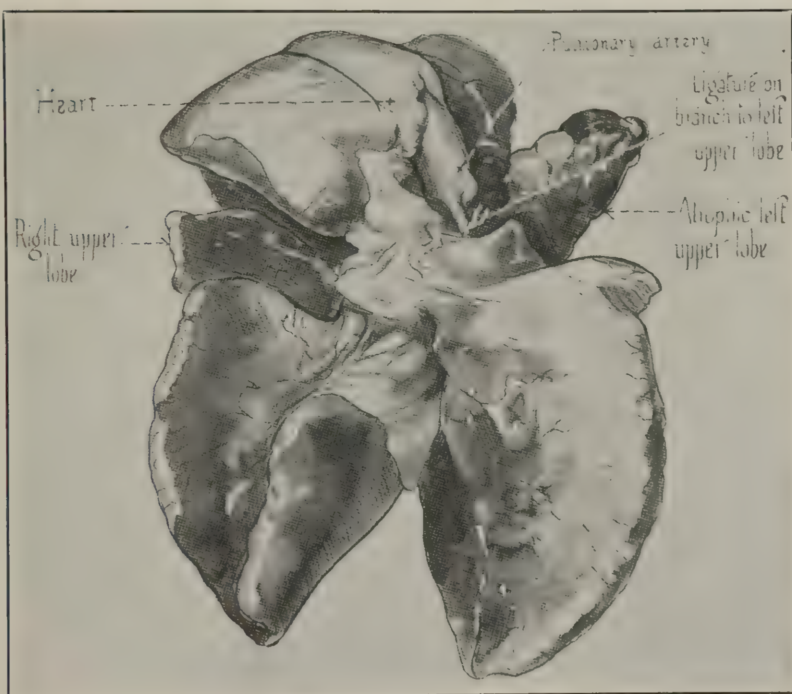

FIG. 181.—Sheep's lung five weeks after ligation of the artery supplying the left upper lobe

than one produced rapidly, and that life is possible when the former exceeds in bulk amounts which are fatal in the latter. The extraordinary dangers of abrupt production of bilateral pneumothorax or the rapid formations of bilateral pleural effusions are well known, even to laymen. Graham and Bell,[5] working with animals of the thin pleura type, in which, unlike man, a unilateral pneumothorax can not be maintained, found that the evil effects of the rapid bilateral reductions in intrapleural negative pressures could be measured by the size of parietal defects. Other experimental evidence has been presented to indicate that if negative pressures are reduced sufficiently gradually, almost normal inflation of the lung can be maintained when parietal defects are created subsequently.

All of these manifestations can be explained physiologically. Nature attempts to maintain suitable areas of alveolar air and blood requiring aeration in order to protect external respiration on which life depends. Should intrapleural negative pressures be reduced sufficiently gradually in a competent individual, there is reason to believe that redistributions of blood in both circuits and increased blood pressures can by action through the air cell-capillary gear maintain full normal inflation after the negative pressures are neutralized. When negative pressures are so rapidly reduced in the competent that compensatory adjustment can not be made, or gradually reduced in the incompetent, who are unable to make adjustments, corresponding grades of deflation are caused.

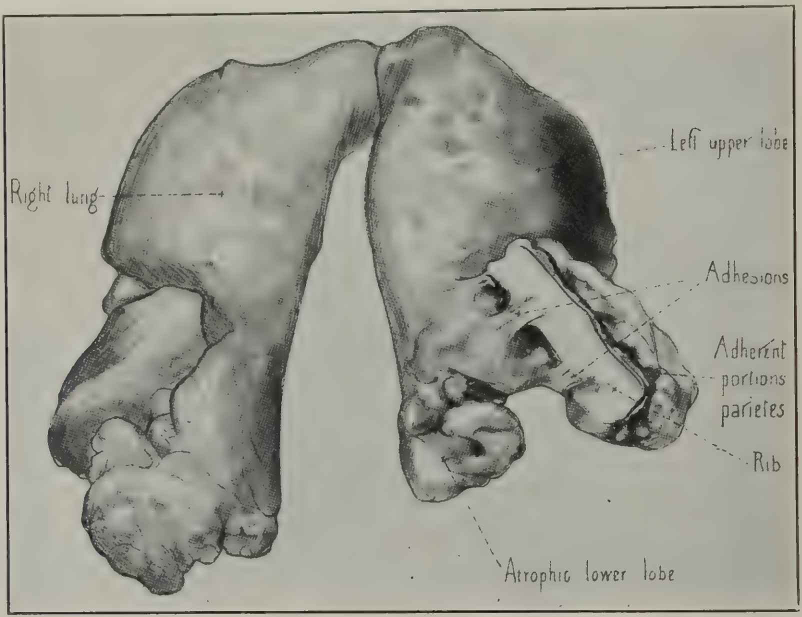

FIG. 182.—Sheep's lung five months after ligation of the artery supplying the inferior margin of the left lower lobe, showing adhesions produced by simple thoracotomy

Pulmonary deflation inevitably measures an equivalent reduction in the corresponding pulmonary blood supply. It should be recalled that the pulmonary circulation is not provided with an effective vasomotor control. The blood normally destined to reach an area of deflated lung is delivered to the nearest area in which the intracapillary pressures will permit circulation to occur. Wherever an increased amount of blood is driven through pulmonary capillaries there is produced a corresponding degree of inflation, a compensatory emphysema. Thus, if the area of deflation is small, the compensatory emphysema will appear in the same lobe; if larger, in the same lung; if larger still, in the opposite lung. Compensation is produced by the amounts and pressures of blood delivered and is, therefore, most effective in the virile. Limitations of compensatory pressures can be estimated in the weak by determining reductions in circulatory competence as well as by measuring the deficit in vital capacity.

These are nature's methods of maintaining the air alveolar capillary blood relationships that underlie external respiration. The effectiveness of the relationships is measured by vital capacity. If it is less than the tidal air of rest, life is impossible; if equal, bare existence is possible; and as it exceeds the tidal air of rest, it measures the margin of safety, the limits of possible physical and mental activities, including defense and repair.

External Compression

Collapse is the deflation caused by the elastic recoil of lung when intrapleural negative pressures are neutralized. The amount of deflation is controlled by the opposing forces, the blood pressures in the pulmonary and bronchial arteries. External compression is produced when a force exceeding the pressure of an atmosphere acts on a lung from without and produces a grade of deflation corresponding to the preponderance of compressive force from without the lung over the expansive resistance of the blood pressures within the lung. On the release of external compression the lung reexpands to the grade of deflation due to collapse. This is often noted when chronic pleural exudates are divided or removed or when pleural effusions are removed.

Deformity of chest walls, intrathoracic tumors, aneurysms, intrapleural transudates, exudates, spontaneous and artificial pneumothorax, thoracoplasty and intrathoracic operations are causes of compression. An outline of changes produced by the common cause, pleuritic exudates, suffices for all.

Exudates formed in a pleural cavity free from adhesions eventually gravitate. Should they increase, the lung is floated upward so far as its hilum attachments permit. As the level of the fluid rises out of the costophrenic sinuses, the lung is elevated and negative pressures are reduced to zero after which external compression begins. It is exerted first on the supra-adjacent lung. This is exactly contrary to the effects of diaphragmatic contractions, which diminish pressures on supra-adjacent lung, and are readily seen fluoroscopically in the zone of increased inflation just above a contracting diaphragm.

Pulmonary vessels carrying low pressures are easily compressed; air cells are smaller; and this zone of lung becomes proportionately inactive physiologically so that the bronchial arterial blood supply is also correspondingly reduced by the usual vasomotor responses. The same series of changes, becoming more and more accentuated, develop as the exudate increases. With increasing exudation, the significant adaptive changes become more noticeable.

At first, compression of the pulmonary circulation diverts blood to the nearest margin of lung under less compression and creates there a zone of physiologic emphysema in the same lobe. Gradually, this extends to higher lobes and finally to the contralateral lung. Thus are produced zones of skodaic resonance and the contralateral emphysema long noted with pleuritic effusions.

Should the exudate form rapidly, as it often does in streptococcus infections, patients may succumb in a few hours because of their inability to deliver the requisite blood pressures to continue the adaptive emphysema. Physiologic emphysema, be it recalled, is merely a natural method of developing a sufficiently large area of functioning alveolar epithelium in one part of a lung to compensate

for reductions elsewhere, and thus to provide enough external respiration to support life. Again, the exudate may be produced more gradually, and, though it cause complete external compression of the entire lung on the affected side, the patient is able to survive. Moreover, the more gradual productions of exudates are favorable to the formation of adhesions between visceral and parietal pleuræ and thus to localization of the process.

Another point is noteworthy. Intense irritation of visceral pleura tends to produce a subserositis or cortical pneumonitis that may be effective in reducing pulmonary elasticity, which interferes with vital capacity.

There is a parallelism between the adaptive processes in the cerebral and pulmonary circulations neither of which is under direct vasomotor control. Both can compensate for gradually increasing antagonistic pressures remarkably well. Both are lethally incapacitated if the counter pressures rise more rapidly than the patient can develop compensatory rises in blood pressures to offset their effects which are respectively cerebral anemia and impaired external respiration.

Internal Compression

Internal compression differs from external in that the force is exerted within the lung instead of on it. The common causes are chronic passive congestion, pneumonias, tumors, foreign bodies and parenchymatous hemorrhages.

The effects of internal compression are the same as those arising from external compression. They differ in extent and in distribution. Compensatory emphysema develops about a focus of internal compression by the same air cell-capillary gear. The blood being diverted from a focus of greater to surrounding zones of lesser pressures produces an enveloping layer of hyperemia and consequent emphysema. If the foci of internal compression are sufficiently large and numerous, they can produce a manner of skodaic resonance and even lead to contralateral emphysema.

Should the force exerted by foci of internal compression be sufficient, large branches of pulmonary arteries, bronchial arteries or bronchi can be occluded. The effects of such occlusions will be noted later.

Pulmonary Circulation

Abnormalities in the arterial circulation are gradual occlusions of pulmonary arteries producing equally gradual increments in peripheral resistance, sudden occlusions of larger branches by injuries, ligations and emboli causing abrupt increments in peripheral resistance.

Gradual occlusions or obstructions to arterial circulation occur in chronic external and internal compressions of the lung in pleural effusions, tuberculosis, bronchiectasis and pathologic emphysema. High peripheral resistance leads to hypertension in the pulmonary circulation by extraordinary exertion of the right heart which results in hypertrophy and diminished reserve power. This explains why individuals so affected are especially sensitive to sudden changes in intrathoracic pressures and why all grades of pulmonary compression should be minimized.

Sudden occlusions or obstructions to main branches of the pulmonary artery are produced by ligation and by emboli. They cause a sudden shunting of considerable volumes of blood into other vessels and an abrupt rise in peripheral resistance. A strong individual tolerates such a change without notable variations in pulse rate or systemic blood pressures. A weakened heart may be incapacitated almost immediately. Permanent occlusion of a pulmonary artery causes atrophy, shrinkage and atelectasis in the lung affected. Ligation has been practiced and is still advocated in treating tuberculosis and bronchiectasis. It is in effect a physiologic lobectomy when the principal artery to a lobe is tied. But it does not cause gangrene or infarction because the parenchyma and visceral pleura are supplied by the bronchial arterial circulation.

Experiments indicate that life is possible after four-fifths of the pulmonary arterial circulation has been destroyed in successive stages, as in repeated lobectomies. Sudden occlusions of much more than three-fifths are incompatible with life.

Two erroneous notions about the effects of pulmonary embolism are prevalent. One is that embolism is the cause of gangrene and infarction of the lung; the other, that deaths from emboli can always be attributed to their size.

Embolism can be an indirect cause of gangrene or infarction if it produces secondarily enough internal compression to occlude a bronchial artery. Usually, gangrene and infarction are occasioned by thrombosis in pneumonia or occur in lungs with circulatory impairments incidental to cardiac lesions or consequent on pleural effusions.

The victims of pulmonary embolism expire or they recover, perhaps to die later of pneumonia. Survivors suffer only from such ill effects as may be attributed to a physiologic lobectomy. Deaths from pulmonary embolism in debilitated patients are often due to emboli sufficiently large to raise peripheral resistance abruptly above the limits of their restricted powers of cardiac compensation. There are, however, many deaths of relatively healthy individuals, as, for example, a few weeks after a simple herniotomy, which fail to be thus explained. Barcroft[6] has suggested that an embolus can be caught close to one of the nerve endings present in the pulmonary arterial wall and may, by irritation, interfere reflexly with normal cardiac impulses.

Operative removal of pulmonary emboli has been recommended and, in one instance, has been accomplished without killing the patient. Removal of emboli could not be sufficiently prompt to obviate the sudden deaths. It could therefore only be employed to rehabilitate a fraction of the pulmonary circulation or prevent embolic pneumonia. The very patients needing to have a portion of their pulmonary circulation restored are those so debilitated that thoracotomy would be a fatal burden. None could say that any given embolus was going to cause metastatic pneumonia, or that its removal would prevent the pneumonia or would help to reduce the dangers of septicemia. Hence, the removal or attempted removal of a pulmonary embolus is almost without exception a highly dramatic example of surgical malpractice.

Interference with the circulation in the pulmonary veins is due to obstructions caused by incompetence of the left heart or resulting from pulmonary compression. Both add to peripheral resistance in the pulmonary circulation.

If the obstruction develops abruptly, and the use of positive pressure with too great anesthesia is a nice example, acute cardiac dilatation is constant and often fatal. Acute venous obstruction can become so critical that systematic venesection is indicated. Gradually increased obstruction leads to chronic passive congestion with its series of handicaps. Abrupt increments in chronic obstruction can cause edema of the lungs.

Bronchial Arterial Circulation

Bronchial arteries carry six times the pressure of the pulmonary artery, and, as stated, supply the major part of nutrition to lung parenchyma and visceral pleura. Hemorrhage from rupture of the bronchial artery into a bronchus causes exceptional deaths with hemoptysis; into a lung, the diffuse parenchymatous hemorrhagic infiltration called splenization. Obstruction of this blood supply can produce infarction and gangrene. The principal significance is surgical. Splenization is commonly a positive indication to excise the portion of lung affected. Incisions and resections of lung require accurate ligation of severed branches of the bronchial artery which are easily recognized by the spurting of red blood. Usually, it is safest to remove all lung bereft of its bronchial arterial blood supply.

Bronchial Air Circulation

Obstruction of bronchi deprives the corresponding lung of its supply of air and assures atelectasis because the air present at the time obstruction occurs is rapidly absorbed. Commonly, an obstruction of larger bronchi leads to pneumonia through infection added to the pressure exerted by retained secretions.

The surgical significance is clear. Bronchial defects must be repaired accurately, and, when such repair is impossible, the corresponding lung should be removed.

Pneumonias

The more acute and diffuse the inflammation, the greater and more abrupt is the internal compression and increase in peripheral resistance in the pulmonary circulation. Processes of this type are more apt to be accompanied by restricted movements of the diaphragm on the affected side, which are almost certainly inhibited if pleurisy develops. The danger lies chiefly in the extra load thrown on the right heart in addition to the burdens of myocardial injuries from toxemia. It is particularly desirable to reduce the expenditures of energy by the heart. Benefits of early and repeated aspirations of pleural exudates introduced years ago by Bowditch [7] are too important to be neglected. Occasionally, the diaphragm is but little affected. Paralysis obtained by injecting the phrenic nerve can be helpful. The main obligation is to reduce cardiac labor in order to aid compensation and to increase pulmonary blood supply.

Chronic pneumonia reduces pulmonary elasticity and increases peripheral resistance in the pulmonary circuit.

Emphysema

Pathologic emphysema means reduced pulmonary elasticity, increased peripheral resistance in the pulmonary circulation and a limited capacity for compensation. It commonly indicates a narrower margin of safety than would be suspected. The right heart has been working for a considerable period against abnormally high peripheral resistance, and its store of reserve energy is subnormal. The bronchial arterial supply is reduced, and the powers of resistance and repair in both parenchyma and visceral pleura are accordingly restricted.

Intrathoracic operations on patients suffering from emphysema are extraordinarily hazardous. Such patients are likewise less able to tolerate pleural effusions and should be protected by early and repeated aspirations, preferably by continuous one-way drainage.

Atelectasis

Lung becomes atelectatic when its supplies of air or of blood from the pulmonary artery are stopped. It is physiologically inactive and receives the least blood through the bronchial arteries. Such lung atrophies and is cicatrized, both leading to contraction. Contraction is powerful enough to carry with it adjacent lung so that an area of atrophy, which is but a part of a lobe, may reduce the whole lobe to a small mass puckered about the hilum.

In the performance of intrathoracic operations, this must be considered. Lung that has become permanently atelectatic or is likely to become so is more safely excised as a rule.

Observations of the actions and reactions in the breathing and circulatory units occurring under physiologic and pathologic conditions show that nature attempts to maintain such interrelationships as will assure preservation of the basic function of external respiration with the largest margin of safety therein.

Control of the basic relationships, namely volume of ventilated air, area of alveolar epithelium, expanse of capillary endothelium and unit volume of blood, is in part in the central nervous system, but to a larger extent is vested peripherally in the air cell-capillary gear.

Vital capacity measures the efficacy of the relationships so that, in effect, nature strives to maintain a high normal vital capacity, a lead that therapy must follow.

Vital capacity is determined in the last analysis by the integrity of the pulmonary circulation affected by and affecting the state of the breathing unit. Preservation and rehabilitation of the pulmonary circulation, the quality, quantity and pressures of the blood delivered by it, are the most important part of intrathoracic therapeutics.

NATURAL DEFENSE REACTIONS

Nature's methods of meeting irritations from injury or disease by increasing resistance and hastening repair through reduced but not inhibited function are more evident and perhaps more significant in the chest than elsewhere.

Irritations affecting thoracic parietes or viscera almost constantly restrict parietal movements. Costal excursions may be more affected than diaphrag-

matic or vice versa. Both are influenced because there is a common control. This is well illustrated if one side of the diaphragm is paralyzed by blocking the cervical portion of the phrenic nerve when there is an immediate, if transient, limitation in the costal excursions on that side.

The effects of restricted motion are to encourage somatic rest, to conserve energy, to limit dissemination of irritants and to prevent atrophy and hyphemia inevitable with nonuse. They may be noted in parietes, in lung and in pleuræ.

Restricted motion in extrapleural parietes subject to irritation is of no especial moment other than assuring the richest blood supply compatible with minimal expenditures of energy.

Restricted motion in the parietes has very definite influence on the lungs. When restricted motion is considerable, as in more intense types of irritations, the diaphragm is more or less relaxed and is prone to be forced by intra-abdominal positive pressures into an unusually high position. Pulmonary excursions are thereby reduced, and more important still, the total volume of lung or the grade of inflation is less. It has been found experimentally that a lung in approximately a mean position between extremes of inflation and deflation produced by inspiration and expiration receives the largest unit volume of blood with the least cardiac effort. Under such conditions the vessels are neither elongated nor tortuous and peripheral resistance is lowest. It has also been found that under these most favorable conditions pleuropulmonary resistance to infection is highest, and the rate of repair and functional rehabilitation is well-nigh doubled.

The effects of restricted parietal motion on the visceral and parietal pleuræ are significant since pleurisy is commonly the cause and frequently the danger of treatment. The parietal pleura receives its blood from the same vessels that supply the adjacent parietes so it is helped by restricted parietal motion. The visceral pleura is more effective in defense against pleural irritations than the parietal because it has a richer blood supply and a larger expanse. The gravity of serositis in general is determined by the excess rate of production of effusions over the rate of their absorption. Resistance of serous cavities is commensurate with their ability to maintain visceral and parietal reflections of serosæ in apposition by absorption of exudates. Absorption from the pleural cavity is notoriously slow and slower still if visceral pleura is incapacitated by compression of exudates. Lung in the mean position between inflation and deflation provides its pleural surface with its richest blood supply. Hence, through diminished parietal motion, Nature protects the welfare of parietes, viscera, and pleuræ.

Besides the foregoing adaptations in the breathing apparatus, there are responses in the circulatory unit. Satisfactory determinations of rates of flow and pressure of blood within the pulmonary circulation are yet to be made. Blood is forced through the lesser circuit in one-fifth the time under one-sixth the pressure required to drive it through the systemic. Fluctuations in blood pressure occur, perhaps synchronously with variations in systemic pressure, but are less in extent. Presumably, the margin of safety in the right heart

is as wide as in the left. However, nothing definite is known of the persistence and effects of pulmonary arterial hypertension.

Shunting of blood from one part of a lung to another or to the contralateral lung is attributable in the main to hydrodynamic influences. Anatomists have found nerve cells indicating possible vasomotor controls, but physiologists have not demonstrated corresponding functions. However, two peculiar reactions occur that may be caused by such influences. Massive collapse of an entire lung has followed injury to the opposite side of the chest. Such lung must be deflated, and deflation can result only from failure of air to enter the bronchi or from interference with delivery of blood through the pulmonary arteries. Massive collapse might be explained by a unilateral temporary occlusion near the bifurcation of the trachea were it not for the second reaction. Surgeons who have performed open thoracotomy without the protections from differential pressures have noted a sudden lateral shifting of the mediastinum which has been called fluttering or epilepsy of the mediastinum. This has been found experimentally to be associated with equally sudden variations in intrapleural negative pressures, and, in the absence of tracheal obstruction, was attributed to shunting of blood from one pulmonary artery to the other. Conceivably, such shunting might be explained by alternating kinking and unkinking of the pulmonary arteries, but alternating vasometer spasms seem more plausible.

TREATMENT

The object of treatment is to protect and to restore the function of external respiration, which is estimated by the vital capacity. The means are to assure the integrity of both the circulatory and the breathing units. Available methods are few.

Circulatory Unit

Abnormalities occur in the amount and distribution of blood in an organism. If the amount of blood has been reduced by hemorrhage or as the result of increased blood destruction or decreased hematopoiesis, prompt relief is attainable with transfusions. If the amount of blood in circulation is reduced because of exemia or the escape of plasma into the tissues, benefits follow intravenous administration of hypertonic glucose which may be given with and without insulin or with and without gum acacia. Each has its indications.

The importance of overcoming shock or states bordering on shock can be illustrated experimentally. If a robust dog is bled from a femoral artery until the heart stops, and an open thorax is then created promptly, the heart beats again for a considerable interval and more blood escapes from the artery. If, however, a dog in a state of prolonged and profound shock is similarly treated, the heart is not reactivated. In other words, little or no reserve blood is stored in pulmonary vessels during shock. Immediate compensatory or adaptive responses are impossible. Additional demands for oxygen can not be met because an important cog in the mechanism of external respiration is not working; hence, the need for providing an ample blood supply before attempting an operation and avoiding pulmonary compression, so far as possible, if that operation is intrathoracic.

Breathing Unit

Means to counteract lesions in the breathing apparatus are extrapleural and intrapleural.

Extrapleural procedures can restrict parietal movements, increase pulmonary deflation or produce compression.

Lesser degrees of restricted movements of the parietes can be obtained by bandages, swathes, and adhesive plaster, particularly if it is remembered that adhesive plaster splints are fully effective only when snugly applied, corsetlike, around the entire chest. Frequently, desirable benefits can be secured by further increasing the spontaneous restrictions to motion, particularly if the lung is placed simultaneously in that stage of deflation wherein the blood supply is most favorable. Then, benefits may be provided readily by section of the cervical portion of the phrenic nerve, if permanence is required, or by injecting it with cocain or with appropriate dilutions of alcohol should subsequent regeneration be desirable.

Extrapleural thoracoplastic operations are effective in producing permanent compression to aid in obliteration of cavities, particularly in tuberculosis and some forms of bronchiectasis. Failures of these operations, if patients are properly selected, can be attributed to insufficient costal resections or to having attempted too much at one stage.

The operations are dangerous because the patients are usually weakened by a losing struggle against an affection that is mainly unilateral, and during operation they must lie on the sounder side. A more serious handicap is cardiac incompetence. Increased peripheral resistance in the pulmonary circuit has resulted from the internal compression caused by the lesions. It is usually of long duration and has sufficed to reduce the margin of safety especially in the right heart. Fever, intoxication and anemia add burdens by causing myocardial degeneration. It is obvious why excisions of parts of only a few ribs can so alter distribution of blood in the pulmonary circulation that the greater labor required to effect compensation can lead through progressively increasing tachycardia to lethal myocardial exhaustion.

Rest, digitalis, transfusions and intravenous administrations of glucose can be extremely valuable in surgical preparation. The greatest assurance of safety lies in performing these operations in stages with sufficient intervals to permit orderly readjustments in the circulatory apparatus. One stage too many is preferable to one stage too few. An incompleted operation can provide the dangers and distresses of a finished procedure without affording the benefits.

Intrapleural procedures are called closed when free pleural surfaces are not exposed to the air and open when they are so exposed.

Closed methods are drainage afforded by single or repeated aspirations or by the continuous removal of exudates accomplished by air-tight, intercostal tube drains, artificial pneumothorax and thoracotomies performed through preformed adhesions. The same sources of danger are present in all. One is the sudden entrance of air into free pleural space. The other is caused by rapid and forceful operating. Both have the same effect, abrupt changes in

intrathoracic pressures which require immediate readjustments in the pulmonary circulation. Likewise, the same precautions are to be observed. Aspirations and drainage through tubes should be gradual. Artificial pneumothorax should be induced slowly and at repeated sittings so/that intrapleural pressures are progressively reduced before positive pressures are created. Accurate hemostasis and gentleness are essential in closed thoracotomies.

Empyema will continue to be an important part of intrathoracic therapy. The best treatment is prevention, which means early diagnosis and immediate aspiration as first advised by Bowditch.[7] Fluoroscopy, essential to both, has been insufficiently practiced and is more generally available since bedside roentgen-ray units have been made easily portable.

Early aspiration, perhaps closed drainage, even if it fail to abort empyema, can minimize its severity, extent and the necessity for rib resection. More important still, it reduces the persistence of diaphragmatic paralysis, which Pryor[8] showed to be so common and Middleton[9] found to be commensurate with reduced vital capacity and degrees of disability. Moreover, pulmonary deflation with its added burdens on the pulmonary circulation are minimized during aggressive phases of pneumonias when a slight shift in the patient's favor can obviate a fatality.

Rib resections impair parietal mobility and are to be avoided whenever possible. On the other hand, it is usually unwise to delay performing this operation after the application of ordinary surgical principles indicates open drainage. Much may be accomplished by the use of surgical solution of chlorinated soda (Dakin's solution) to dissolve fibrin and by employing gentian violet as advocated by Keller,[10] to disintegrate fibrous tissue.

After-care has been too often neglected. As soon as the acute process permits, breathing exercises are needed to stretch adhesions, to reactivate the diaphragm and to develop compensatory physiologic emphysema in order to maintain a high vital capacity.

Discussion of open methods for treating intrathoracic lesions is limited to consideration of ways of performing thoracotomy in the absence of pleural adhesions. Incisions should be designed to assure permanent air-tight healing, else open pyothorax is inevitable. It is the principal cause of postoperative disabilities and deaths. Differential pressure is required for safety. Analgesia suffices. Both can be obtained by the proper use of gas-oxygen as developed by Gwathmey.[11] It is wise to inject the phrenic nerve with 1 per cent cocaine. The immediate paralysis of the diaphragm makes operation easier and hastens recovery. There is less postoperative discomfort as the effects of cocaine last for four or more days. Effusions are more rapidly absorbed because the pulmonary blood supply is richest under these conditions and healing of lung tissue is favored. Operators differ in respect to drainage. Postoperative pleuritic effusions are constant, commonly of considerable volume, are slowly absorbed and offer a favorable medium for bacterial growth. They cause pulmonary compression and its train of evil influences. Air-tight drainage is possible, is effective, and is seldom to be regretted. Omission of drainage can be disastrous. While suturing the wound at the end of a thoracotomy,

it is important to obtain air-tight closure with lungs in full inflation and to obtain it in such a manner that the stitches may not cause tension necroses.

After-care, if otherwise it can be called such, includes breathing and body exercises to restore parietal movements, pulmonary elasticity, and intrapleural negative pressures as steps in the rehabilitation of external respiration which can be measured by frequent estimations of vital capacity.

SUMMARY

Life and activities are made possible by external respiration which is provided through coordinated actions of the breathing and circulatory units.

Coordinated actions of breathing and circulatory units maintain sufficient volumes of ventilated air in contact with a suitable area of alveolar epithelium to assure such interchange of gases through a similar expanse of capillary endothelium as will aerate equivalent amounts of blood. The interrelationships between the volumes of ventilated air, the area of alveolar epithelium, the expanse of capillary endothelium and the amounts of blood needing aeration must remain constant although they are constantly fluctuating with each breathing cycle and with variations in activities of the individual.

This constancy is assured under normal conditions by an arrangement of an air cell-capillary structure and function whereby fluctuations in degrees of inflation produce equivalent fluctuations in amounts of blood, and vice versa.

Under abnormal conditions, the relationship is modified through the air cell-capillary gear, so that additional areas of alveolar epithelium and of capillary endothelium are provided to compensate for such as may be temporarily or permanently inactivated.

External respiration in a normal individual is undisturbed whether he is at rest or exercising full mental and physical powers. Disability is nil, and the limits of activities, including defense and repair, are measured by normal vital capacity.

External respiration in persons affected with incompetent breathing or circulatory units is impaired. This impairment restricts the development of mental and physical powers to the level at which the relationships between ventilated air, areas of alveolar epithelium, expanse of capillary endothelium and amounts of blood can no longer be kept constant. There is disability corresponding to the level. Activities including defense and repair are proportionately restricted, and the restriction is measured by the reduction in vital capacity.

Preservation of vital capacity during the acute phases of diseases affecting the thorax and its contents and restoration of vital capacity thereafter are the therapeutic objectives.

Vital capacity measures external respiration which is largely under control of the air cell-capillary gear. Treatment seeks to renew parietal mobility, to reestablish normal intrapleural negative pressures and to restore pulmonary elasticity, at the same time providing for deliveries of suitable amounts of good blood by the right heart and preventing obstruction to the pulmonary circulation through incompetence of the left heart. The specific aim is to rehabilitate the air cell-capillary gear in order to secure the largest measure of external respiration. Achievement is measured by vital capacity.

CONCLUSION

The principal effects of intrathoracic diseases are the malfunctions due to lesions of heart and lungs. Both heart and lungs are possessed of remarkable powers of compensation and repair but, when seriously affected, cause enormous totals of distress, disability and death. Many lesions of heart and lungs from which spontaneous recovery is impossible can be remedied surgically by procedures already devised.

A wider application of known methods and the introduction of new procedures can be hastened by more exact knowledge of intrathoracic structures and functions.

At present, vital capacity is significant in estimating latent powers including defense and repair, in determining therapeutic procedures and in measuring results of treatment.

Vital capacity is regulated by the air cell-capillary gear, the weaker part of which is the circulatory segment. Progress in intrathoracic surgery depends largely on the realization of more effective measures to promote and to conserve the integrity of the pulmonary circulation.

APPLICATION OF BIOLOGIC PRINCIPLES TO THORACIC INJURIES

The actions, reactions, and adaptation of the breathing and circulatory units above described will be discussed in reference to thoracic injuries in particular. Repetition, even though fatiguing, will emphasize the biologic principles underlying treatment, which, if correct, will be permanent however much methods may be improved.

Thoracic injuries affect the parietes alone, the viscera alone, or, most frequently, both parietal and visceral lesions are produced. Hemorrhage and the exposure of lacerated tissue to air and to infection, which occurs with all wounds, are of special significance because of the untoward effects of hemopneumopyothorax.

Chest injuries, severe enough to need treatment and not causing prompt death, produce an immediate defense reaction, restricted motion, particularly of the injured side or the side of greater injury.

The virtues of restricted motion in respect to defense and repair are twofold. The blood supply exceeds deliveries made when there is immobilization. Continued limited motion, an incomplete interference with function, assures opportunities for the earliest and most complete restitution of function.

Thoracic parietes are benefited by a narrowing of intercostal spaces. Tension upon soft tissues is reduced, a richer blood supply is favored and the size of tissue defects is minimized. Simultaneously, diaphragmatic excursions are curtailed, first, through spasm; later, through relaxation due to fatigue, which, in the presence of intra-abdominal pressure, carries the affected side to an unusually high position. Some motion, even when there is paralysis of one side of the diaphragm, is provided by a contralateral tug with each inspiration so that here, too, conditions favorable to healing are provided.

Diminished motion of the parietes, and particularly of the relaxed diaphragm, not only decreases pulmonary excursions but also lowers the mean

pulmonary inflation. Hence there is a diminished volume of lung subjected to less motion. Observations made by Steiner[12] upon patients suffering from irritations to lung and to the visceral or parietal pleuræ, even before pneumonitis or pleuritis is demonstrable and though they may never develop, prove this reduction in size and motion of lung to be a natural defense reaction. Experimental evidence (Cloetta)[13] shows that these conditions provide for delivery of the richest blood supply to a unit volume of lung, and, quite as important, with the least expenditure of cardiac energy.

Pleural defense and repair is obviously affected by the same conditions since the blood supply to the parietal reflection is derived from the vessels supplying the chest wall and the diaphragm and the visceral layer is nourished (in man) chiefly by the bronchial arteries.

Pulmonary inflation is also affected through injuries to the circulatory mechanism by hemothorax, by intrapulmonary hemorrhage and by variations in the volume and force of the blood delivered to the lung.

Hemothorax, usually accompanied by some pneumothorax, is the commonest complication. Blood, escaping from either visceral or parietal lacerations into a pleural cavity free from adhesions, tends to settle in the costophrenic angles so that intrapleural negative pressures are reduced and progressive degrees of collapse occur before the lung volume is affected by direct pressure. As the level of the extravasated fluids rises, pressure is exerted chiefly upon the contiguous lung which is also elevated. When the extrapulmonary pressure exceeds the tension within the pulmonary arteries, that portion of the lung is deflated. At the same time the blood which should have been delivered to the zone of lung under compression is shunted to the superadjacent lung, wherein, because of the air cell-capillary gear, a margin of compensatory emphysema is produced. This emphysema produces the Skodaic resonance constantly recognizable above the level of pleural effusions. Should the hemorrhagic extravasation continue to increase, the same compensatory changes are augmented so long as the circulation remains competent. However, a point will be reached at which the excess blood diverted from the compressed lung can no longer be distributed only to homolateral lung, but will in part be shunted to the lung in the opposite side of the chest. Here will be produced by the same air cell-capillary action the contralateral emphysema so commonly noted with large pleural effusions and massive pulmonary consolidations.

When unilateral negative intrapleural pressures are nullified—i. e., equal to the atmospheric pressure—the lung is in a position of collapse or as it would be with an open thorax. Intrapleural pressures in excess of the atmospheric produce degrees of pulmonary compression which vary directly with the amount of positive pressure exerted upon the lung and indirectly with intrapulmonary intravascular tensions. The final state, complete, rapidly produced unilateral compression, is seldom compatible with life and therefore rarely encountered.

From a practical standpoint it is wise to examine these adaptations more closely. However they may be produced, by variable proportions of hemothorax, pneumothorax and pleuritic effusions, as unilateral intrapleural pressures grow progressively more positive, they are met, as has been shown experimentally,[3] by increments in systemic blood pressures within the lesser circulation.

So long as intravascular tension within a lung exceeds the extrapulmonary pressure the unit volumes of blood delivered will remain approximately normal, but such deliveries are secured by a greater expenditure of cardiac energy. When the extrapulmonary pressure exceeds the intrapulmonary vascular tension, there occurs the inevitable shunting of blood from zones of greater to the nearest zones of lesser compression. The compensatory emphysema inevitable with increased blood deliveries assures proper aeration of excess blood, but it is obtained at the cost of increased cardiac labor which is proportionate to the adaptations demanded and is effective so long as circulatory competence persists.

Possibilities for compensation vary within wide limits. Our observations have shown that a competent circulation in man will adjust itself to an abrupt interruption to the blood supply of an entire lung without recognized embarrassment. A healthy monkey will tolerate an increase in unilateral intrathoracic pressure exceeding twice the atmospheric pressure without giving indications of immediate distress. On the other hand, dogs, in which neither unilateral pneumothorax nor unilateral hydrothorax can be maintained, have not such powers of adjustment. They can barely tolerate atmospheric intrapleural pressure and then the better when slowly induced so as to provide opportunity and time for a compensatory rise in blood pressures. When their heart muscle is fatigued by meeting repeated demands for compensation, dogs can tolerate progressively less reduction in negative pressure. Similarly, a fatigued monkey or a man handicapped by myocardial deficiency, hemorrhage or shock, may be unable to withstand even atmospheric pressure, although gradually induced.

Another complication due to lesions in the circulatory apparatus is intrapulmonary hemorrhage, which may arise from lacerated pulmonary arteries or veins or from severed bronchial arteries. Resultant interstitial extravasations reduce pulmonary elasticity and affect pulmonary inflation. The results vary from localized hematomas to a diffuse brawny infiltration or splenization that may involve an entire lobe and is in effect an infarction.

Intrapulmonary hemorrhages cause intrapulmonary compression, and, like extrapulmonary compression, compel a shunting of blood from foci wherein intravascular tension is exceeded to surrounding lung wherein it is not exceeded, so that the same factors are active in causing compensatory emphysema.

Incompetence is the most significant of all injuries to the circulatory unit whether produced by myocardial deficiency, anemia or exemia alone or in combination, because of the limitations to compensations that make external respiration possible. So important is this phase of the problem that it is fair by way of emphasis to anticipate therapeutic discussion and state that those procedures offering the greatest immediate protection to the lesser circulation and the largest possibilities for its rehabilitation, both measurable by vital capacity, are most effective in intrathoracic therapy.

SURGICAL METHODS

The aims of civil and of military surgery are identical, to provide the largest opportunities for functional recovery with the least danger, delay, and distress. Handicaps imposed by warfare too frequently restrict what

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should be done to what can be done. Makeshift methods need not be discussed as they are born of unfavorable conditions and individual ingenuity. Interest centers in means to a satisfactory performance of thoracotomy under field conditions, for thereby alone can many of the severely wounded be saved from death and a very large proportion of all the wounded be returned promptly to duty.

Surgeons have been enabled to invade body cavities effectively by first learning to control subsequent inflammation of the lining membranes of those cavities. This is particularly true of the thorax. Appreciation of the need to control pleuritis by restricting pleural irritation and by conserving the defensive and reparative powers of the pleura is simultaneous with the realization that the great majority of deaths not immediately due to injury and much of the late disability are attributable to acute and chronic pleural inflammation.

The explanation is simple. Chest wounds provide all of the conditions favorable to the development of pleuritis, tissue laceration, unyielding costal parietes, hypertension due to hemothorax, exudation more rapid than absorption, foreign bodies, and the presence of bacteria. Acute pyothorax added to burdens of recent wounds and exposure is an extremely serious complication, particularly when, as often occurs, circumstances prevent adequate personal attention to the sick. Chronic pyothorax, even though treated as superbly as has been done by Keller,[10] inevitably causes material disability.

Methods for controlling pleural irritation should cooperate with natural defense reactions. Mesothelium lining serous cavities, compared to other tissues, is exceptionally resistant to irritants and possessed of correspondingly high powers of regeneration, provided its blood supply is adequate.

The extent and character of serositis is determined by the intensity of irritations, their dissemination through motion, capillarity, and gravity, by the hypertension produced within the cavity and the subserous reactions which curtail the supply of blood. In other words, resistance of serous activities is commensurate with their ability to maintain their mesothelial surfaces in approximation. This depends upon a greater rate of absorption than of exudation and upon flexible parietes.

Pleural resistance is relatively lower than peritoneal because the rate of absorption of pleural effusions is less rapid than the rate of exudation and because parietal adaptability is virtually limited to the various positions which may be taken by the diaphragm.

A major portion of pleural resistance is borne by the visceral reflection and this is subject to material reductions by the interferences with the circulations in the lung consequent upon injury. As already stated, the total volume of blood delivered to a normal lung is commensurate with activity of respiration and with circulatory competence. If, as the result of extrapulmonary pressures (air, blood, exudate) or intrapulmonary pressures (interstitial hemorrhage), the pulmonary arterial pressure is surpassed, deflation occurs which amounts eventually to atelectasis when blood flow is inhibited. By the same token, if a large branch of the pulmonary artery is occluded, permanent atrophy of the lung supplied thereby is the result (figs. 181, 182). Presumably, in areas

of partial or complete deflation and in atrophy the bronchial arterial blood supply is proportionately reduced. If the bronchial supply is withheld, necrosis follows. Although Karsner and Ghoreyeb [14] have shown that when the pressure in either the pulmonary or bronchial circulation is reduced to zero, blood may pass over from one to the other, it was not evident in wounded human lungs that this interchange was free enough to be effective. Therefore, in man, because the visceral pleura is supplied by the broncial arteries, the basic need is to maintain a degree of pulmonary inflation compatible with function because the bronchial arterial blood supply varies directly with functional activity.

Natural defense reactions indicate that the limited degree of inflation determined by reduced costal excursions and the high position of a relaxed diaphragm is the most propitious. According to Cloetta,[13] the pulmonary vessels in a lung thus inflated are neither tortuous, as in greater deflation, nor elongated, as in great inflation. In consequence, lungs thus inflated contain the maximum unit volume of blood delivered with the least cardiac effort.

Rapidity and extent of dissemination of intrapleural irritants are well illustrated by a simple hemothorax. As first demonstrated experimentally by Denny and Minot,[15] and confirmed by the observations of Elliott and Henry [16] upon the wounded, intrathoracic movements are sufficiently active to defibrinate the blood in the pleural cavity which does not coagulate promptly and to spread the exudate over the entire pleura free from previous adhesions. Delrez [17] and Middleton [18] showed that blood is so irritating to joint and chest serosa as to produce a serofibrinous serositis. Middleton [18] found the chief irritants to be fibrin and fibrinoplastic substances. Not all of the latter are removed when coagulation occurs so that serum remains an active irritant.

These facts explain the diffused pleural reactions, varying from a serofibrinous to an organized exudate, noted when a thoracotomy is performed hours, days, or weeks after a hemothorax has resulted from injury. They also help to explain why pleuritis must be combatted otherwise than peritonitis. Generalized pleuritis is the rule; generalized peritonitis, the exception. Thoracic parietal adaptability is restricted to the diaphragm; abdominal parietal adaptability is only restricted beneath the costal angles and in the pelvis. In both healing occurs by adhesions between irritated surfaces which must be in apposition. Hence routine drainage of the general pleural cavity, which is possible if properly done, is indicated, and attempted drainage of the general peritoneal cavity, which is physically and physiologically impossible, is contraindicated.

Irritation of serosa provokes a very rapid serous effusion which occurs promptly with hemothorax and soon exceeds the amount of blood originally present. High position of the diaphragm is a constant accompaniment of hemothorax (Bradford,[19] Elliott,[16] Soltau [20]) and is due at first to inhibition of contractions and later to paresis. Steiner's [12] observations upon the early effects and Pryor's [8] studies of the late effects of pleuritis show that the early upward displacement of the diaphragm is almost constant and tends to persist rather than to recover unless specially treated.

The effects of pleuritis above mentioned are intensified by the presence of bacteria and their toxins. When the pleuritis is intense it provokes a cortical

subserous pneumonitis unless the lung be so devoid of circulation that reaction is impossible, and then, like a foreign body, it is an added burden to defense. Moreover, even when a lung is but partially compressed its circulation is inadequate for defense because it is only under such conditions, according to Karsner and Ash,[21] that pulmonary embolism causes infarction.

The effects of collapse and compression of the lung upon the circulation, particularly the burdens thereby added to the heart, have been described. It is only necessary to add here that heart muscle, recently compelled to overexertion, is particularly susceptible to intoxication. Hearts, already fatigued and still compelled to work disadvantageously, tolerate so poorly even the limited absorption from pleuritic effusion that the margin of safety is widened if their physical load is reduced by pulmonary reinflation which decreases peripheral resistance notwithstanding greater absorption of toxins from the pleura through the improved circulation. Moreover, the improved circulation also raises local resistance and favors repair.

Basic Principles in the Treatment of Thoracic Injuries

The capability of maintaining its lining membranes in apposition is a gauge of its powers of absorption and roughly measures resistance of a serous cavity. Accumulation of fluid or air means dead space, hypertension within the cavity, diminished blood supply and decreased resistance, and in the chest, added cardiac labor. Methods of treatment, which prevent separation of serous surfaces, or, after separation has occurred, reestablish and maintain surface contact, provide the best opportunities for immediate recovery, of course assuming that circulatory incompetence is given proper attention.

The degree of ultimate recovery is determined by the promptness and completeness of restoration of function. Since the identical factors controlling respiration affect the circulation, measures must be adapted to restore mobility of the parietes, especially the diaphragm, to reestablish normal intrapleural negative pressures and pulmonary elasticity.

The most important part of treatment is restriction of pleuritis; the next most important is overcoming the effects of pleuritis. If these demands are given due consideration, no essential detail will be omitted. The specific objectives are four:

(1) *Parietal healing.*—Permanent air-tight parietal closure is imperative, because the worst complication is open pyothorax, particularly if it occurs early and before the formation of limiting adhesions. Smooth healing of parietal pleura is especially advantageous. It limits pleural effusions and offers the most effective barrier to the extension of inflammation, the usual antecedent to open pyothorax, either from within the chest to the parietes, or vice versa. Also it is the best protection against persistent or recurrent empyema.

(2) *Restriction of pleural effusions.*—Pleuritic effusions interfere with all of the factors which together make normal respiration possible and they likewise decrease pleural resistance. They can be restricted by reducing pleural irritation but not enough to be absorbed as rapidly as they form. Their removal is

always desirable and often imperative and may be accomplished without ill effects by closed (air-tight) drainage.

(3) *Pulmonary inflation.*—Underinflated or overinflated lung adds to cardiac labor and narrows the margin of safety. Lung tissue that can not be inflated, or, if inflated, can not remain inflated, is without function and therefore without the blood supply essential to defense and repair. In general, such tissue is a direct menace and should be removed.

(4) *Pleural adhesions.*—Early fibrinous adhesions are inevitable and desirable. They limit the progress and extensions of pleuritis. Experience in combating peritoneal adhesions and the work of Delrez [17] and of Willems [22] in overcoming adhesions following arthritis have proved that the principle of inducing active motion as early as the infectious process permits and of continuing it to the limit of pain inhibition gives the best functional results. The same principle applied in the treatment of pleurisy is equally efficacious. The anatomic explanation for the return of function is the persistence of some more or less isolated mesothelial cells of the serosa beneath exudates, even after organization has occurred. If motion disrupts adhesions gradually and without causing hemorrhage, the mesothelial cells which have been exposed by the disruption can, because of their extraordinary regenerative powers, overgrow the adjacent tissue defects. Thus is made possible restoration of a pleural cavity after pleuritis which can be so perfect as to permit of normal function.

If these four points are kept constantly in mind, the details of treatment to be described will appear less petty. Attention to details secured the tissue repair upon which recovery of function depends, and when neglected, as was at times imperative during periods of stress, the average of results obtained was less satisfactory.

TYPES OF CHEST INJURIES

Injuries to the thorax affect the parietes alone, both the parietes and viscera, or, more infreqently, the viscera alone. The last are due to indirect violence, or to sudden and considerable changes in atmospheric pressure resulting from near-by explosions. Wounds, perforating, penetrating, or tangential, are similar to those involving other structures, but are distinguished by one peculiarity—their liability to produce an open thorax. They are also complicated by wounds of the abdomen and spine more commonly than are wounds elsewhere.

In general, shell fragments cause greater tissue injury than bullets, and more commonly carry other foreign bodies and bacteria with them into the tissues. The physical injuries of the thorax are of the same type as injuries elsewhere; they include a central zone of tissue destruction, an intermediate zone of tissue injury, and a surrounding zone of hemorrhagic infiltration, which merges into an outer margin of active hyperemia in the tissues still capable of defensive reaction. They are subject to the same bacterial contamination, the same implantation of foreign bodies, as are other wounds.

Injuries of the Thoracic Parietes Alone

These comprise about 10 per cent of chest wounds, and consist of contusions, lacerations, and punctures, with or without simple or compound frac-

tures of the ribs, scapula, clavicle, or sternum. They are caused by crushing injuries, by the direct impact of spent missiles, and most commonly by tangential injuries from various types of projectiles.

In general such injuries require the same treatment as similar wounds elsewhere—thorough cleansing and a resection of the necrotic and dangerously devitalized tissues. The most important details are to avoid opening the pleural cavity and to protect the parietal pleura from infection. Contused skin and subcutaneous fat do not heal well, particularly if suture is necessary. As a rule wide cutaneous resections are avoidable, but when indicated some plastic flap closure can be made.

Except in the muscles of the erector spinæ group and the muscles attached to the scapula, there is relatively little danger of gas gangrene, because chest muscles are not surrounded by unyielding structures, and are less liable to the pressure anemia caused by swelling after injury or by the constriction of bandages. As a consequence less radical excisions of injured portions of the chest musculature are required than in similar injuries elsewhere.

Fractures are treated upon general principles although in compound fractures of the ribs particular care is necessary to resect damaged tissues widely and to avoid additional injury to intercostal structures. Injuries to nerves and blood vessels about the clavicle are repaired as accurately as possible.

Perforating wounds of the parietes occurring so low in the lateral aspects of the chest as to affect only the costophrenic sinuses may occasion negligibly slight intrathoracic disturbances, and yet they may require thoracotomy to effect deep transpleural repair.

Injuries of the spine without cord lesions require particularly careful excision because of the liability to infection due to muscle injury and the presence of bone fragments. Lesions of the cord may demand laminectomy. When paralysis is complete, efforts to obtain primary healing are particularly desirable in order to reduce subsequent distress.

Injuries Involving Both Parietes and Viscera

In 10 per cent the visceral injuries are due to force transmitted from the parietal injury without penetration of the parietal pleura. In the remaining 80 per cent the visceral lesion is caused by projectiles or indriven rib fragments. In these it is important that an air-tight closure of the pleura be secured whether it has been opened by the primary injury or at operation.

Variations in methods of operating upon wounds of the chest wall, from those outlined above, are determined by the extent of intrathoracic injury, the necessity for performing thoracotomy, and the general condition of the patient. Whether the parietal pleura is opened by the primary injury or at subsequent operation, a permanent air-tight closure is essential.

Ideal repair of defects in serous membranes is obtained by an accurate approximation of serous surfaces without undue tension, because anything foreign to serous surfaces, including other living tissues, is an irritant. When the defects in the parietal pleura can not be closed by approximation, as frequently occurs with multiple rib injuries, makeshifts must be provided. The best substitute for parietal pleura is visceral pleura. Distended lung is easily

stitched to the margins of the defect in the parietal pleura. Injuries low in the flanks quite often require this type of closure; frequently the diaphragm must be utilized, either alone or in conjunction with the visceral pleura. Adhesions about an injured area of serosa are unavoidable and their immediate establishment by suture is sometimes desirable to reduce subsequent intrapleural effusion. The next best substitute for parietal pleura is accurate apposition of the smoothest obtainable muscle surfaces. Failing these a covering can be obtained by using a pedicled skin flap.

Wounds of the diaphragm are always serious because of added intra-abdominal complications and occasional pericardial involvement. Those on the right side are commonly associated with a flow of bile from the injured liver into the thorax, which is generally followed by a severe empyema. On the left side there is liability to diaphragmatic hernia. On both sides there may occur a back flow of urine from injured kidneys.

Diaphragmatic defects are best closed so as to effect a smooth approximation of intrathoracic serous surfaces. On the right side the edges of diaphragm everted against the lacerated liver aid in hemostasis; on the left, the irritation from exposed muscle is better tolerated by the peritoneum than by the pleura. Excision of lacerated edges of wounds in the diaphragm need not as a rule be extensive and should be as limited as conditions permit. Lockwood and Nixon [23] believe that repair of these wounds is more important than that of any hollow or solid abdominal organ. Transpleural repair of the diaphragm is usually simple and accurate; transperitoneal repair may be impossible.

Considerations of injuries to thoracic contents may be almost restricted to wounds of the lung. Cardiac, intramediastinal and vascular injuries seldom come to operation. The effects of traumatism, direct and indirect, upon the lung are intrinsic and extrinsic, as they occasion pressure upon and irritation to the surface by hemothorax and inflammatory exudates, or pressure within the parenchyma through interstitial infiltration with blood or transudate and by pneumonia. Tissue destruction, injury, and infection of the lung are of relatively little importance because of the natural resistance of lung tissue and its remarkable powers of repair, provided it has an adequate blood supply—a factor determined principally by the degree of compression. Operations upon the lung are required to protect the pleural cavity and to make possible an immediate resumption of respiration, rather than to prevent complications in the lung itself.

Injury to the lung, whether caused directly by a projectile or an indriven rib fragment, or indirectly by the impact of a high-velocity projectile, or by sudden variations in atmospheric pressure, is evidenced by parenchymatous bleeding. If the parenchymatous injury is superficial and extends through the pleura a hemothorax results. Bradford [19] showed that the injured lung is the principal source of hemothorax.

Though some hemoptysis is constant, intrapulmonary hemorrhage due to laceration of the pulmonary artery is mainly interstitial and usually is limited, since lung tissue is capable of a high degree of spontaneous hemostasis for bleeding from pulmonary vessels. Hemorrhage from a freely opened bronchial artery, carrying six times the pressure of the pulmonary circulation, produces

a very much more extensive infiltration before the extravascular tension suffices to check the bleeding.

Interstitial hemorrhage may vary from a slight, limited, plum-colored effusion, which barely interferes with normal aeration, to a true, bright red, traumatic infarction or splenization. The danger from splenization arises from its interference with aeration and with pleural blood supply. Experimental evidence in this respect (Plate IV) confirms clinical observations. If this brawny hemorrhagic infiltration extends to the pleura, an intense reaction results. If such an area can not be aerated with the aid of increased intratracheal pressure, the affected portion of the lung is probably permanently injured, even if it be viable. The immediate danger is the production of empyema, a danger sufficient to warrant excision of the affected lung if recovery is doubtful.

Wounds of the large bronchi are seldom seen, as they are usually associated with rapidly fatal injuries. Such wounds when not immediately fatal and those in which lacerated tissue either in lung or parietes has a valve-like action and permits air to be forced or aspirated into the pleural cavity with each inspiration and not expelled at expiration produce the rare examples of extensive pneumothorax. A limited pneumothorax constantly accompanies lung wounds. Occlusion of a large bronchus causes not only a complete atelectasis of the corresponding lung, but leads to a fatal bronchopneumonia and purulent pleurisy by damming back secretions in the affected lung structures. Occlusion of a smaller bronchus causes only an atelectasis in the portion of lung supplied by that bronchus, which is evanescent if the obstruction is not permanent. Compression of bronchi, possibly in part due to muscle spasm, aided by the presence of intrabronchial mucus and blood, leads to a peculiar type of collapse, particularly where there is added some degree of external pulmonary compression. A part of a lobe or an entire lobe may be affected. The lung is flat and quite bloodless, the pleural surface is in puckered ridges, and it feels like meat. Reinflation is impossible. There is, as a rule, an associated crushing injury of the overlying parietes without direct injury of the affected lung. This type of injury, carnification, demands excision. Infection of such tissue with anaerobes is the usual cause of the stinking types of pulmonary gangrene.

Wounds of the pericardium and heart and of the vessels within the mediastinum are rarely seen at operation. Hemopericardium, in addition to causing serositis, diminishes the effectiveness of the heart action by the pressure exerted. This is demonstrable experimentally, leads to reduction in blood pressures, and is in effect identical with the cardiac tamponade of pericardial effusion.

Injuries Involving Viscera Alone

These are limited to pulmonary collapse and intrapulmonary hemorrhages, with or without a complicating hemothorax. Their treatment by conservative or radical methods is determined by their severity.

EXPERIMENTAL SPLENIZATION IN A DOG'S LUNG. THE THICK FIBRINOUS EXUDATE WHICH FORMED OVER AREA OF SPLENIZATION IN TWO DAYS INDICATES A DEFENSIVE REACTION AGAINST THE IRRITANT. LIGHTER COLORED PORTION TO LEFT IS NORMAL LUNG; DARKER COLORED PORTION TO RIGHT IS LUNG INJECTED BY BLOOD FLOWING FROM A BRACHIAL ARTERY THROUGH TUBE AND ASPIRATING NEEDLE. LOWER PICTURE IS A SECTION AT LEVEL OF DOTTED LINE IN UPPER PICTURE. THE VISCERAL PLEURA CAN BE TRACED FROM LEFT TO RIGHT. BELOW THE PLEURA IN THE AFFECTED PORTION IS THE SPLENIZED LUNG; ABOVE IT IS THE FIBRINOUS EXUDATE THAT FORMED IN TWO DAYS AND THAT ILLUSTRATES THE INTENSE REACTION TO AN IRRITANT THAT MIGHT HAVE BEEN CONSIDERED ALMOST INNOCUOUS

PREOPERATIVE PHYSICAL DIAGNOSIS OF CHEST INJURIES

Of paramount importance in determining the approximate extent and nature of intrathoracic injury from a missile or a bayonet thrust is an appreciation of the anatomic relationships with particular reference to surface landmarks and the vital underlying structures. Anatomic models or charts will eliminate much uncertainty in plotting the course of a missile between known points of entrance and exit. Deflection by bony structures and alterations in the relationship of intrathoracic organs occasioned by changes in intrapleural pressure must enter into the proper evaluation of this determination.

Alterations in the contour of the chest and displacement of the cardiac impulse are common results of intrapleural accumulations. Obliteration of interspaces may arise under the same circumstances whether the accumulation be fluid or air. The respiratory movements should be carefully analyzed in their component factors, costal and diaphragmatic. Aside from the definite changes which would arise from alterations in the position of the diaphragm, the inhibitory influence of trauma on the movements of the chest, either directly or remotely applied, must be borne in mind.

In general, the remaining physical signs are dependent upon air content and sound transmission. Air content, elicited by percussion, may be either increased or decreased in chest wounds. Increase in air content is denoted by a lower pitched (hyperresonant or tympanitic) note and, resulting from a thoracic injury, indicates emphysema or pneumothorax. Reduction in air content leads to a higher pitched (impaired to flat) note and under the present consideration suggests a pleural accumulation of fluid (blood or chyle), intrapulmonary hemorrhage, or pulmonary collapse. In differentiating these conditions the position of the heart is helpful. Pneumothorax and fluid accumulations in the pleural cavity lead to definite cardiac displacement toward the opposite side. Displacement of the heart toward the side of the altered note suggests massive pulmonary collapse. Cardiac displacement is unusual in emphysema and uncomplicated intrapulmonary hemorrhage.

The final consideration in the diagnosis of intrathoracic injuries devolves on the question of the transmission of sound vibrations as determined by the palpating hand and listening ear. Alterations in tactile fremitus, breath sounds and vocal resonance are dependent upon changes in the conducting media between the larynx and the parietes. All conditions introducing new media of conduction or interfering with the normal channels of transmission, viz. the bronchial tree, tend to reduce or obliterate fremitus, breath and voice sounds. Thus fluid or air in the pleural cavity will decrease sound transmission by the introduction of an added medium, while intrapulmonary hemorrhage leads to the same result usually by obstruction of the bronchi. An apparent departure from this rule will be discussed under the reversed circumstance, namely, reduction of the media of conduction. Obviously, when the media of sound transmission are reduced, fremitus, breath and voice sounds are increased. For the sake of clarity, an approach of breath and voice sounds to the basic type in the larynx or trachea is considered an increase irrespective of pitch. Unification of media, such as occurs in pneumothorax with a patent

bronchus, is attended by a great increase in tactile fremitus, breath sounds (cavernous) and voice sounds (pectoriloquy). Furthermore, certain cases of pulmonary infarction and of massive collapse may show by reason of a unified medium either increase or decrease in these signs of sound conduction dependent on patency or occlusion of the communicating bronchi.

Further development of the physical signs in chest wounds from these fundamentals are suggested by an appreciation of the physics and the pathologic physiology of fluid and air accumulations in the pleural cavity. Skodaic resonance, movable dullness, succussion splash, egophony, whispering pectoriloquy, metallic tinkle, and bell tympany are to be considered in this relation. The peculiar crackle of mediastinal emphysema was first described in the chest wounds of the Great War.

INDICATIONS FOR OPERATION

The problem may be reduced to two fundamental questions: Does the injury warrant intervention, particularly intrathoracic intervention? If so, what methods are indicated?

Immediately arise the questions of diagnosis and of prognosis. The nature of intrathoracic injuries can be more accurately and rapidly determined by fluoroscopy than by any other means. The prognosis may be established at the same time.

Injuries involving the chest wall alone usually cause a reduction of motion upon the affected side, and can easily be mistaken for penetrating or perforating wounds if the patient is not examined fluoroscopically. The danger in injuries of the thoracic walls lies in the liability to subsequent pleurisy by extension, if infection with a virulent organism develops. This danger can be reduced by immediate excision, which is rarely to be regretted and is too often a source of serious consequences if omitted. Exploration of the tracks of rifle bullets showing clean wounds of entrance and exit frequently reveals severe tissue lacerations and unsuspected rib fractures, and occasionally also discloses foreign bodies in addition to the tar drop blood clots constantly present.

Wounds of the parietes associated with intrathoracic injuries, even more than those involving only the parietes, demand accurate excision and primary suture to prevent the development of empyema. The larger the wound and the greater the destruction, the greater the urgency for intervention. Differences of opinion arise over the treatment of lesser injuries. Injuries to the lower margins of the ribs often cause hemorrhage from the intercostal vessels with bleeding into the chest. Penetrating or perforating wounds caused by small shell fragments and bullets not infrequently cause incomplete fractures of the ribs, with the result that bone fragments are driven through the pleura, perhaps into the lung. Even at the wound of exit from the chest bone fragments may project into the pleural cavity, and the intercostal vessels be injured. These slight rib injuries can not be recognized under the fluoroscope, and frequently escape detection when plates are made. Their significance lies in the fact that bone fragments are the most dangerous foreign bodies. From these considerations it is evident that virtually all wounds of the chest wall should be treated by radical operative methods, though not necessarily by thoracotomy.

Indications for performing thoracotomy to cope with intrathoracic lesions are three: (1) Those based upon preoperative findings; (2) those based upon operative findings; (3) uncomplicated hemothorax.

INDICATIONS BASED UPON PREOPERATIVE FINDINGS

This group includes retained foreign bodies, unless very small, particularly if they are free in the pleural cavity; extensive splenization (Duval)[24] or serious hemorrhage appearing externally; suspected wounds of the diaphragm (Lockwood and Nixon);[23] and acute infection (Gask)[25] which can be assumed when treatment is delayed.

INDICATIONS BASED UPON OPERATIVE FINDINGS

Gask[25] in particular advocated proceeding with operation within the chest when parietal operation disclosed serious internal lesions. Duval's axiom, "The general rules of surgery must be applied to wounds of the lung," gained wider recognition as benefits attainable by operation were realized.

Hemothorax.—If hemorrhage may be called a wound complication, hemorrhage is the commonest and most important complication of chest injuries. Reports upon thoracic injuries by internists center about hemothorax, its physical signs and symptoms, the best time and method of aspiration, and the late complications. Lockwood and Nixon[23] saw its dangers, although they felt the dangers were insufficient to warrant thoracotomy. Gask[26] in a post-bellum report was unprepared to say that simple hemothorax of moderate size should be treated by operation. At the close of the war there was a growing sentiment in favor of open operation in the treatment of extensive hemothorax, particularly if massive clotting had occurred. Aspiration remained the method of choice in treating limited hemothorax as it led to early recovery and return to duty.

The arguments against operative treatment of hemothorax are that conservative treatment, early aspiration with air replacement as practiced by Bastianelli,[27] or aspiration after 7 to 10 days, with or without oxygen replacement, gives better results, particularly a lower immediate mortality rate, and reduces the pressure upon surgical facilities during periods of active fighting. The indications from the standpoint of morbid physiology are definitely for the earliest elimination of pleural irritation and pulmonary compression, the inevitable consequences of hemothorax and pneumothorax.

Hemothorax is of itself seldom sufficient to cause death either through pressure or acute anemia. The large amount of bloody fluid which is present after a few hours, its dilution as compared to normal blood, its liability to increase after active hemorrhage has ceased, prove that a pure hemothorax has a transient existence, and that it is only a few minutes before a secondary pleuritic effusion is added. In the presence of clots there is still more intense irritation, a fact which led Elliott,[16] Davies[28] and others to advocate open operation for their removal.

Later results of hemothorax are equally serious. Bradford[29] noted a decreased absorption rate of fluid and gas from the pleura attributable to the fibrinous exudate. Delayed absorption of hemothorax has been repeatedly mentioned, and, according to Davies,[28] it is far from being the exception.

Absorption is not always promoted by aspiration, as evidenced by the example reported by Tuffier[30] of a hemothorax which persisted for 15 months in spite of 27 aspirations.

As the result of pulmonary compression, vicious adhesions, thickened pleura, and an immobile diaphragm, there is deficient expansion, shoulder drop, scoliosis, parenchymatous sclerosis (Tuffier),[30] and incapacitating dyspnea. The dyspnea may last for months or even years, and, according to Leslie,[31] is largely dependent upon the degree of permanent collapse of lung tissue.

The possibility of secondary infection of a hemothorax adds another and more dangerous complication. Gask[25] found that nearly all war wounds are contaminated. Soltau,[32] in his bacteriologic studies of empyema, found gas-producing organisms in 48 per cent, streptococci in 40 per cent, and organisms from the lungs in 12 per cent. According to Elliott,[16] one-fourth of the hemothoraces became septic no matter what type of missile caused the wound; of these one-half died, and one-third of those who recovered were invalided out of the service, making a total of 16 per cent in which death or incapacity was due to infected hemothorax. Moreover, it is difficult to recognize the presence of infection in a hemothorax since a simple hemothorax usually runs a febrile course and because the bacteria, as pointed out by Leslie,[31] may be in the clotted portion of the exudate, so that the fluid portion obtained by early aspiration may be sterile. Open drainage was generally held to offer the best chance of recovery from this type of pleuritis though closed drainage would have been more efficacious. Gask[25] recommended thoracotomy with mechanical pleural cleansing and immediate closure. Statistics are not available to indicate the proportion of the 75 per cent of hemothoraces which did not become infected and yet contributed to death and incapacity through pleural irritation and pressure. The total loss in man power due to hemothorax alone can be reasonably estimated at 25 to 35 per cent of those receiving intrathoracic injuries.

If it be granted that thoracotomy has become a safe operation, then cumulative evidence indicates that immediate open operation is the sane treatment for all but the limited degrees of hemothorax, even if restricted to the removal of the liquid and coagula. In addition the lung injuries can be accurately repaired, foreign bodies removed, the inside of the thorax inspected and needed attention given to additional injuries not otherwise recognizable. It is still more significant that after these precautions have been taken the lung may be inflated to normal limits and the chest closed, with an immediate return of nearly normal respiration and circulation, factors which provide the most favorable conditions for defense in a contaminated pleural cavity and assure the earliest resumption of activity.

The splendid results reported by Bastianelli[27] in treating chest wounds by immediate aspiration and air replacement, reinforced by the wide acceptance of the value of artificial pneumothorax in the treatment of certain types of pulmonary tuberculosis, demand a reasonable answer.

According to Bastianelli, the cushion of air separating the visceræ and parietal surfaces prevents the formation of pleural adhesions, and the positive intrapleural pressure controls hemorrhage from the wounded lung. Recovery

is prompt because vicious pleural adhesions are prevented, and the repair of the lacerated lung is fostered by immobility and collapse.

Opposed to these theories are definite facts. Air is a serous membrane irritant and elimination of irritation is a basic principle in the prevention as well as the treatment of pleuritis. Positive intrapleural pressure, high enough to stop hemorrhage by pulmonary compression, compresses the homolateral lung, produces contralateral emphysema, and interferes with pulmonary circulation. Compressed lung means contracted lung which is often difficult or impossible of reinflation. If reinflation occurs, a universal adhesive pleuritis is certain. The exact conditions for minimizing the resistance to the flow of blood through the lung, as established by Cloetta,[13] a reduction of mean pulmonary inflation, are met by diaphragmatic paralysis. Diaphragmatic paralysis lasting four or five days can be established by infiltrating the phrenic nerve trunk with 1 per cent cocaine. If this procedure be coupled with closure of the chest without residual pneumothorax, the best conditions for repair and defense have been provided for both lung and pleura.

SURGICAL METHODS

PREOPERATIVE TREATMENT

An individual suffering from a recent chest wound is in need of immediate physical and psychic rest. This can be provided by the administration of a full physiological dose of morphine to reduce coughing and to minimize respiratory effort. Care should be taken in examining and dressing the wound to permit the most comfortable position to be assumed and to avoid exertion on the part of the patient. First-aid should be restricted to hemostasis in the parietal wound and temporary closure of an open thorax. The latter is best accomplished by strapping a firm, thick broad pad over the wound with adhesive plaster, and then fixing a tight swathe about the chest. Provisional suturing of these wounds often leads to tissue emphysema, which interferes with the circulation and materially reduces resistance.

A second dose of morphine is given one-half hour before operation. If there is no question of an abdominal wound, water or hot drinks should be given freely, even just before anesthesia begins. Smoking is a great solace and does no harm if coughing has ceased. Anything to reduce distress is desirable.

Uncomplicated chest wounds are not prone to produce shock, but when there is considerable pulmonary compression they cause a high venous pressure due to interference with pulmonary circulation. If intravenous medication is indicated, it must be given very cautiously in order to protect an overburdened right heart. It is often wiser to give a transfusion of blood after reinflation has been established at operation. A grave anemia is often masked by an unusual distribution of blood because of the reduced content of the compressed pulmonary vessels. A blood transfusion after the evacuation of a large hemothorax and after satisfactory hemostasis has been effected will materially reduce danger.

A diagnosis of the probable nature and extent of intrathoracic involvement is furnished by physical and fluoroscopic examinations. One should

determine if possible the extent of hemothorax and pneumothorax, the presence of extensive intrapulmonary hemorrhage, the presence of extensive clots, the evidence of contralateral injury, the size, position, and motility of retained foreign bodies, the presence of bone injuries, the position and mobility of the diaphragm, the size and position of the heart, and the probable path of the missile.

A moderate-sized hemothorax where there are no adhesions darkens the whole side of a chest as these patients are examined in a recumbent position. Clots when visible are apt to be seen low along the spine and do not move. Intrapulmonary hemorrhages can be seen only when the hemothorax is limited. The shadow corresponds to a lobe and moves with respiratory effort. Contralateral involvement, except for mediastinal displacement, is uncommon. Gask [25] warns against operation when there is evidence of contralateral collapse, but the danger of this complication is avoided when positive-pressure anesthesia is used. The location of foreign bodies is important when they are small and show by transmitted motion that they are close to important vessels or the heart. Otherwise there may be a temptation to omit removing them. Their position usually changes when the chest is opened, but as a rule rule foreign bodies are easily found. Positive evidence of bone injury is valuable; negative evidence is worthless. Its existence must be assumed until disproved by actual exposure at operation. The position and movement of the diaphragm help to determine the presence of injury of that structure and the level of operative incisions.

The heart's position is an excellent index of mediastinal deviation; the size of its shadow may tell of cardiac or pericardial injury. Projection of lines between the wounds of entrance and exit in perforating injuries or between the wound of entrance and the missile in penetrating injuries indicates the structures probably involved. The character of the injuries may be guessed from the size and shape of a retained shell fragment, or, if a bullet, from its shape and path.

ANESTHESIA

It is usually held that the use of differential pressure is unnecessary. The writer does not hesitate to assert that positive-pressure anesthesia, or, better, analgesia, is the most important single factor in successful thoracotomy under war conditions. A full preoperative dose of morphine permits induction of an even, deep analgesia with nitrous oxide and oxygen without increasing the gas-oxygen ration above 3 : 1. This was proved by Cannon's [33] observations to be the limit of safety in the presence of shock. After the induction stage the proportion of nitrous oxide can be reduced occasionally to less than 50 per cent.

The American Red Cross nitrous oxide-oxygen apparatus devised by Gwathmey fulfilled every requirement. A rough gauge to measure the flow of gases, a mixing bag to serve as a pressure indicator, and a close-fitting facepiece are the only essentials. Pressure is furnished from the gas and oxygen tanks, controlled by regulating the flow of the gases, and delivered to the trachea by holding the facepiece snugly in position. The pressure can be

varied as gradually or as suddenly as desired. The physical effort required is not great.

The dangers are real. Anesthetics delivered under pressure are more rapidly taken up by the blood. The more rapid absorption is due to increase in the volume of air containing the anesthetic, in the area of air cell epithelium, in the expanse of capillary endothelium, and in the amount of intracapillary blood due to greater inflation from intratracheal pressure. Anesthetics, when given under pressure in undue concentration, produce toxic effects which can appear suddenly and be rapidly fatal. A second danger is too great pressure. Normal heart and lungs can tolerate an excess pressure, but when the heart muscle and pulmonary circulation are both impaired the margin of safety is much narrower. In general, positive pressure up to 16 mm. of mercury is safe and suffices for all purposes. Beyond that point compression of the pulmonary capillary bed can provoke an acute dilatation of the right heart. A few control observations with a manometer in the circuit show the degree of distention of the mixing bag which corresponds to a pressure of 16 mm. of mercury. It is rarely expedient to exceed this limit.

In practice the analgesia and hypertension are gradually induced with the patient in position for operation (fig. 183). During the induction stage nothing is done to the wound. When deep analgesia has been reached, dressings are cut away and the skin prepared by dry shaving and scrubbing with ether. By this time inflation has been accomplished, so that uncovering a sucking wound occasions little increased respiratory distress.

Various stages of operation can be carried out under the same light anesthesia and the pressure varied as required. Repeated gradual inflation and deflation do not cause variations in the systemic blood pressure which can be detected by clinical methods. Both sides of the chest can be opened without evident distress to the patient. Graham and Bell [5] showed that if an opening in the chest wall of dogs exceeds certain dimensions, the aspiration of air into the lungs ceases. The size of the opening compatible with life in dogs holds relatively true for man provided man's circulation is deficient, e. g., with shock or acute anemia, when the powers of circulatory compensation are materially reduced. The use of positive pressure obviates this complication, as well as most of the coughing and dyspnea which occur when a chest is opened, particularly when a considerable hemothorax is present.

Another important point is the avoidance of traction upon the mediastinum. Traction upon a lung can cause in man a rapid drop of blood pressure of 40 mm. or even more. A deflated lung can not be brought outside of the chest from a position of collapse without traction, but a deflated lobe can be guided toward the thoracotomy opening and delivered without the least traction as inflation is produced.

Clinical results are confirmatory. Patients anesthetized under positive pressure as a rule left the operating room in better condition than at entrance, and the improvement was not evanescent. Operations need not be hurried. After the wound is closed the nitrous oxide is stopped and oxygen under decreasing pressure is given for the few minutes required for a return of consciousness.

Contrary opinions were held by other surgeons, notably Gask,[25] Duval,[21] Depage,[34] and Lockwood,[23] who advocated open anesthesia or local anesthesia. Surgeons using their methods worked in the same units with others who use positive-pressure gas and oxygen analgesia. According to medical officers in charge of chest wards, patients of the former were less comfortable and had a more protracted convalescence.

EXCISION OF PARIETAL WOUNDS

Among the objections to routine excision of all chest wounds are the dangers of anesthesia and the time and extra nursing required. The use of gas as described is a satisfactory answer. Positive pressure is a cure and preventative of pulmonary collapse. Pneumonia after its use is infrequent. Excisions can be done more thoroughly, rapidly, and without the distress of local anesthesia. Accidental opening of the pleural cavity is of little moment, as deflation does not occur and the pleural rent can be accurately repaired.

Disclosure of unsuspected deep injuries is a common experience when parietal wounds are excised as a routine. Frequently a sucking wound is hidden by change of posture so that an open thorax may be suddenly encountered. Parietal excision should always be undertaken with a view to primary closure, because this becomes obligatory if a penetrating wound is encountered.

A satisfactory method of muscle excision consists in splitting between muscle bundles on either side of the injured area and carrying this splitting for some distance in both directions before dividing transversely. This block resection permits the later approximation of smooth surfaces at the point of injury, removes the cut fibers farthest from this point, and interferes least with blood and nerve supply. Excision done in this manner, often so restricted that bruised muscle was retained in order to make closure possible, was not followed in our experience by gas gangrene in chest wounds in a single instance, though gas gangrene occurred in other wounds in several patients who had multiple injuries.

Fractured ribs should be widely resected, and, when possible, the cut ends should be snugly covered with soft tissue, periosteum, or muscle, to reduce the chances of bone infection. Hemostasis may require the use of bone wax. Fractures of the scapula, particularly those caused by shell fragments, are less easily managed. Wide resection is indicated, but the bony framework and periosteum should, if possible, be preserved to make regeneration possible. Denuded bone must be removed; pockets should be collapsed to obliterate dead space. Injuries to the sternum are easily cleansed with gouge or rongeur. Compound fractures of the spine require adequate exposure, radical resections, and great care in removing loose fragments. Bone fragments are the most dangerous foreign bodies in the presence of infection. Excision of skin should secure a clean margin that bleeds freely and nothing more. It is safer to take chances with slightly traumatized skin than to run the risk of necrosis from excessive suture tension.

THORACOTOMY

Positive indications for thoracotomy will generally be recognized before operation. Occasionally a decision will rest upon operative findings. A bullet

may perforate a rib without causing a complete fracture and carry with it splinters of the compact, inner layer into the lung; or, there may be an unrecognized comminuted fracture of the ribs associated with pleural and pulmonary lacerations and only a moderate hemothorax. Similar and even more extensive injuries may be found near the wound of exit. Usually the question is how to proceed rather than whether or not to operate. Three possibilities are offered: First, to do a limited thoracotomy at the entrance and exit wounds, a compromise between radical operation and aspiration; second, to proceed through the wound and resect the ribs widely enough to give the approach needed for deep repair; third, to repair the entrance and exit wounds and then to open the chest through uninjured tissues at a point of election.

By limited thoracotomy is meant: Intrathoracic operations performed through the wounds of entrance or exit with little or no additional enlargement, never enough to permit exploration by the pleural cavity. It is indicated when wounds are small, when destruction is relatively slight, and when the lung can be reinflated. In the absence of or after removal of hemothorax inflation of a deflated lung causes the wounds of entrance and exit in the visceral pleura to approach the corresponding wounds in the parietal pleura. A metal nozzle (fig. 187) attached to a Potain aspirator is introduced through the opening in the parietal pleura, and the fluid blood removed by directing the tip into various dependent pockets while the lung is partly deflated. When inflation is produced the visceral injury floats up to the parietal. If it is small and dry, it need not be repaired. If it is bleeding or if air is escaping, the lung can be secured by forceps at the margin of the wound, and a cone of lung with the wound at the apex can be gently brought out through the opening in the parietal pleura. A purse string suture closure, as in intestinal perforation, suffices. If there has been some rib injury, and bone fragments have been driven into the lung, a small incision through the posterior layer of periosteum exposed by the rib resection will permit excision of the lacerated lung tissue and removal of the bone fragments. After the lung is repaired it is wise to suture the lung wound into the defect of the parietal pleura. Adhesions between these areas are certain under any condition and are restricted by this fixation. This simple method is particularly useful in through-and-through wounds, but less so in penetrating wounds. It can be applied in about 40 per cent of all chest injuries, the proportion varying with the type of fighting. The defects of this method lie in the possibility of leaving clots behind and of overlooking rib fragments.

The majority of more serious chest injuries permit no latitude in selecting the most desirable route for surgical approach. Parietal excision and repair alone are a burden to a man in weakened condition, so that the intrathoracic repair must be attempted by enlarging the wound of entry or exit. This avenue of approach gives a more or less unsatisfactory deep exposure, usually better for diaphragmatic injuries then for pulmonary because a retracted, compressed, and uninflatable lung can not be manipulated readily. As a rule there is a tendency to do too little under these trying conditions. A desire to avoid immediate death of a patient is apt to prevent the removal of injured lung whose presence is incompatible with recovery.

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Methods of gaining deep exposure are determined by the necessity of getting a satisfactory parietal closure. The preservation of parietal pleura is most essential. This layer is no more amenable to plastic surgery than a wet drum head. Each injury is a separate problem, the most desirable solution of which is an approximation of the type of repair described in the elective operation.

Thoracotomy of election is designed to give free access to one side of the chest in order to permit the dislocation and manipulation of each lobe of the lung and repair of the diaphragm. It may be performed before or after the parietal excision, depending upon the type of injury. The chest should be opened on a level with the root of the lung and in a manner favorable to closure. Intercostal incisions are easiest to make but give less satisfactory exposure, and their healing is less certain. Cowell [35] designed a transcostal incision which has much to recommend it when deflation is present, but which is not applicable when inflation is relatively normal. Rib resection can be done very quickly and safely, gives a maximum exposure with minimum damage, and provides the best opportunities for repair. A piece of the fourth or fifth rib longer than the width of the operator's hand is removed so that the mid-point

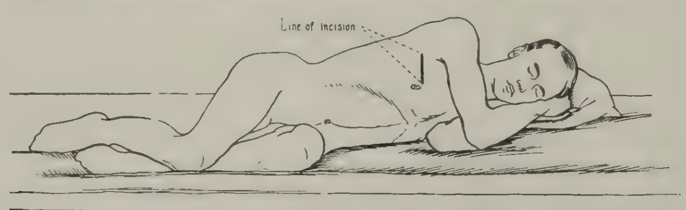


FIG. 183.—Patient in position for operation. Line of incision for a thoracotomy of election

of the defect is slightly nearer the angle of the rib than the sternum. In this area one may secure the maximum effects of rib rotation with the greatest separation for operation and the greatest approximation for closure.

The skin is incised directly over the rib selected (fig. 183) and the rib exposed. A short cut in the lower margin of the pectoralis major permits this muscle to be retracted medially. The latissimus dorsi is easily freed and retracted laterally. The long thoracic nerve can usually be saved. Incision of the periosteum along the midline of the rib is continued posteriorly between the fibers of the serratus magnus (fig. 184). The periosteum is separated with care to avoid injuring the intercostal vessels and nerve. After rib resection the posterior periosteum and parietal pleura are incised along the midline, the incision extending to within a half inch of the rib ends (fig. 187). The release of tension by this incision permits the intercostal muscles to retract and allows the ribs next above and below the incision to be rotated upon their axes and increase the exposure. A wider opening can be obtained by increasing this rotation by outward traction. Exposure thus obtained is quite as good as that provided by a mechanical rib spreader (fig. 186, a.), which crushes the intercostal muscles and thus interferes with subsequent healing. Lockwood [23] believes that the use of rib spreaders adds to shock. A headlight makes it possible to continue most of the intrathoracic work under visual control.

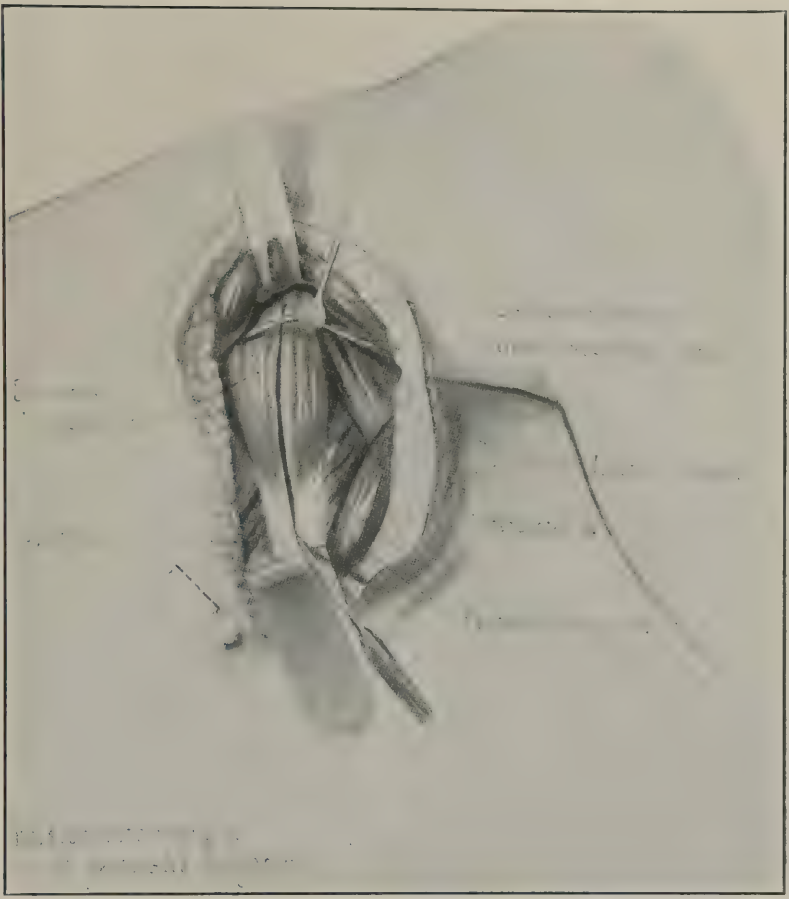


FIG. 184.—Method of exposing a rib for resection. The serratus is excised parallel to its fibers; the long thoracic nerve is retracted posteriorly

FIG. 185.—A, Simple type of rib shears; B, bone biting forceps for chest surgery. The severed bone fragments are held in the bite of the forceps, and can not be sucked into the pleural cavity

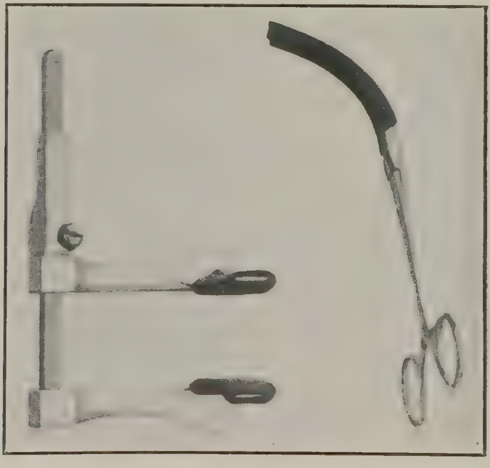


FIG. 186.—A, Tuffier's rib spreader; B, thin-bladed clamp used to secure hemostasis, and as a tractor

It must be borne in mind that this operation is undertaken in addition to excision and suture of the parietal wound or wounds. Its advantages are obvious. The disadvantages are the longer time required and the creation of another wound in the parietal pleura opposite to normal visceral pleura, which assures the formation of dense adhesions in an area where otherwise only slight adhesions would develop (fig. 182).

CLEANING THE PLEURAL CAVITY

Removal of the uncoagulated blood and exudate is effected without delay as clotting occurs very rapidly after operation is begun. A curved metal or glass nozzle (fig. 187) fitted to a Potain aspirator, which is long enough to reach

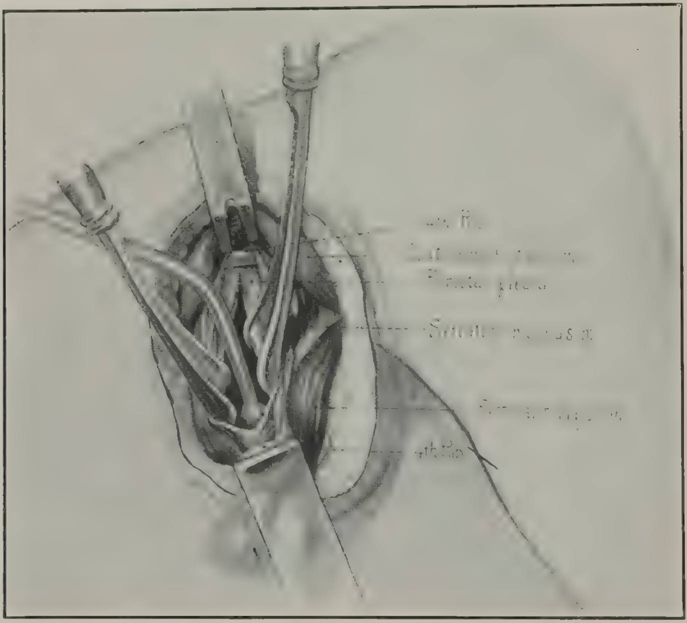


FIG. 187.—Thoracotomy of election. A rib has been resected; the tip of an aspirating nozzle is being introduced into the pleural cavity

all parts of the chest, is satisfactory if the distal end is flanged and protected by a coarse-meshed sieve to prevent the aspiration of large clots which would plug the tube and to prevent injury of the pleura.

The first aspiration is done with the lung deflated in order to facilitate introducing the tip of the nozzle into the various depressions where fluid may accumulate. During the period of deflation it is wise to remove clots which may be covering injuries or foreign bodies and may be less accessible later. Dense clots can be lifted out with forceps or manually. The balance must be mopped out with moist gauze. However gently this is done, an undesirable irritation is produced.

An important part of cleansing is the prevention of soiling. Skin edges should be covered with moist gauze. As soon as the pleura is opened the

parietal wound should be covered with more gauze, which is held in place by the retractors and by clips. The field of operation should be isolated by gauze pads even more carefully than in abdominal surgery.

Thoracotomy, however simple, is followed by the production of excess serous exudate. Every effort should be directed to the limitation of this effusion and to protect it from infection. The chest should be made clean and dry before closure, and no irritants, such as bone fragments, clots, bare ribs, or exposed muscles, should be overlooked. Washing out the pleural cavity is a temptation to be resisted as the subsequent healing is poor. Mopping gently with moist gauze gives the best results.

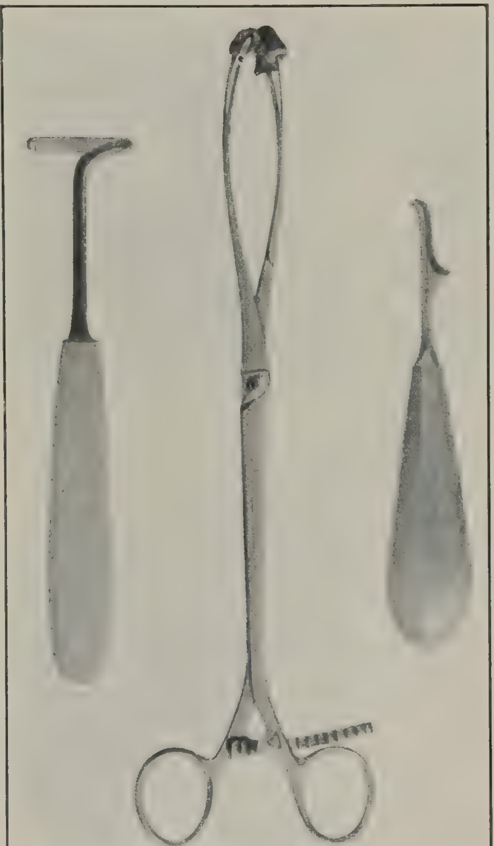


FIG. 188.—A, Cow horn rib stripper; B, Tuffier's lung forceps; C, periosteal elevator

BLOCKING THE PHRENIC NERVE

Natural methods of defense have proved that immobility of the diaphragm provides conditions essential to pleural resistance. These consist in providing an adequate reduction of motion and in assuring the optimum circulation of blood in the lung. Cloetta's [36] experiments show that the least resistance to pulmonary circulation is present when the maximum negative intrapleural pressure is reduced to 2 to 3 mm. of mercury, and that at this pressure the lung contains the largest volume of blood. Middleton [18] found that in dogs an immobilized diaphragm provides this reduction. Experimental and clinical observations prove that recovery from thoracotomy when the phrenic nerve is blocked is more rapid, more certain and less painful than when it is not blocked. Operation is less difficult in the presence of an immobile diaphragm, particularly because acute pneumothorax causes increased respiratory efforts.

One per cent cocaine injected in the trunk of the phrenic nerve causes a paralysis for four or five days. It materially reduces distress by blocking the sensory fibers described by Capps.[37] Novocaine, quinine and urea hydrochloride, and magnesium sulphate are unsatisfactory for this purpose.

When the phrenic trunk can be reached through the thoracotomy exposure, it should be injected before intrathoracic operation is attempted. If it is suspected before operation that intrathoracic injection will be impossible the nerve may be injected in the neck. Cervical exposure of the nerve can usually be

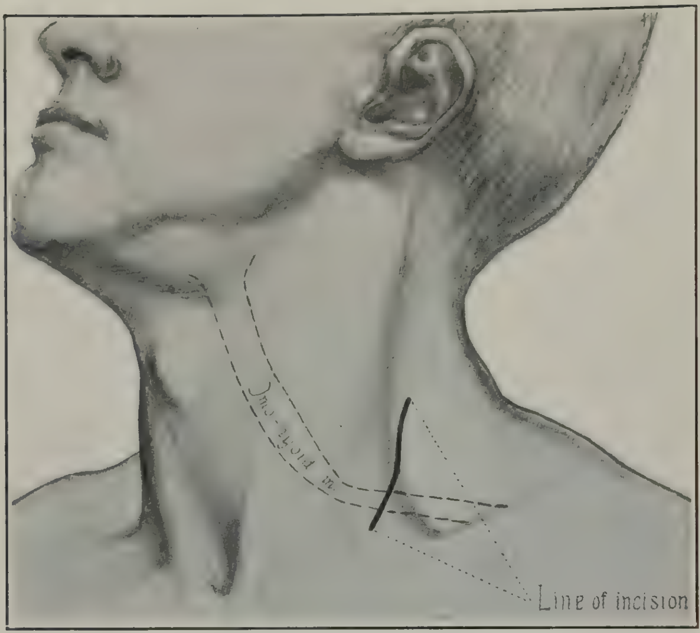


FIG. 189.—Incision for exposure of the phrenic nerve

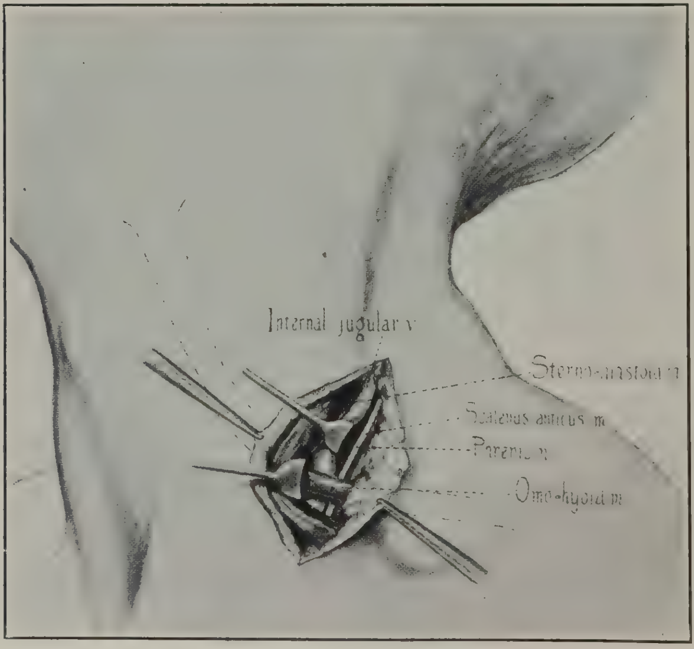


FIG. 190.—Exposure of the phrenic nerve

accomplished with little distress under local anesthesia. The illustrations (figs. 189 and 190) show a larger exposure than required. It may be done largely by blunt dissection with little hemorrhage. Relief of much of the intrathoracic pain following injection of the nerve suggests that blocking of the phrenic nerve should be considered an important step in postoperative treatment, if it has been neglected at operation and convalescence is delayed.

BLOOD TRANSFUSION

The indications for blood transfusion are commonly those of acute anemia, so that intravenous administrations of hypertonic solutions of glucose, with and without gum acacia, tincture of digitalis and insulin are to be considered if suitable donors are unavailable and when patients are suffering from the exemia of shock or need additional protection to their circulatory units subsequent to operation. Transfusion should be started as soon as hemostasis is complete and inflation can be maintained. The blood must be warm and be introduced slowly. No harm comes from transfusion given in this way. Many lives can be saved.

The large amounts of blood and colored fluid removed when the hemothorax is extensive suggest the possibility of aspirating it into sterile bottles containing sodium citrate, filtering, and giving it as an autotransfusion. Tests, however, showed that the attendant risks are prohibitive.

OPERATIONS UPON THE LUNG

Operations upon the lung are undertaken primarily to protect the pleura. Accordingly accurate hemostasis and surgical repair must be obtained in such a fashion that immediate inflation and resumption of respiration may be established in order to insure reapposition of pleural surfaces and an unimpaired blood supply. These conditions require freedom from internal and external compression. In general, lung tissue which can not be inflated or which is devoid of blood supply is actually or potentially a foreign body whose presence is virtually certain to produce or to intensify an empyema. Excision of such lung, whether or not it has been directly injured, must be considered the ideal treatment, and is demanded whenever the location and extent of the affected area indicate the probability that the consequent empyema will be fatal. Our personal experience is the basis for this radical statement. No individual recovered so far as is known where there was failure to excise permanently injured lung. Not all individuals recovered where this excision was done. Post-mortem observations indicated that the excised lung had contributed to the fatality, but not that excision per se could be blamed for the death.

Perforating wounds caused by rifle bullets and small shell fragments require closure of the pleural defects only when there is bleeding or escape of air after reinflation. They can be inverted with a purse-string suture, and should be so inverted if they are accessible. Penetrating wounds are similarly treated. The missile is usually found without difficulty and frequently lies close to the surface. A small pleural incision and a little blunt dissection with

a pair of forceps makes removal easy. Small shell fragments close to big vessels should be carefully removed to obviate the dangers of late hemorrhage.

Large lung wounds are usually caused by tangential violence and are surrounded by more hemorrhagic infiltration than the smaller wounds resulting from more direct impact. The amount of excision required is determined by the degree of internal compression (infiltration). If the lung reinflates completely, trimming the shaggy margins of the defect with scissors and wiping them off with gauze is sufficient. If there is a zone of splenization about the wound which does not inflate or bleed freely, resection must be carried back to margins which are comparatively normal. It is not merely the repair of lung parenchyma which is to be considered. The integrity of the corresponding visceral pleura is of far greater immediate significance and is assured only if the circulation and, therefore, the function of the subjacent lung is restored.

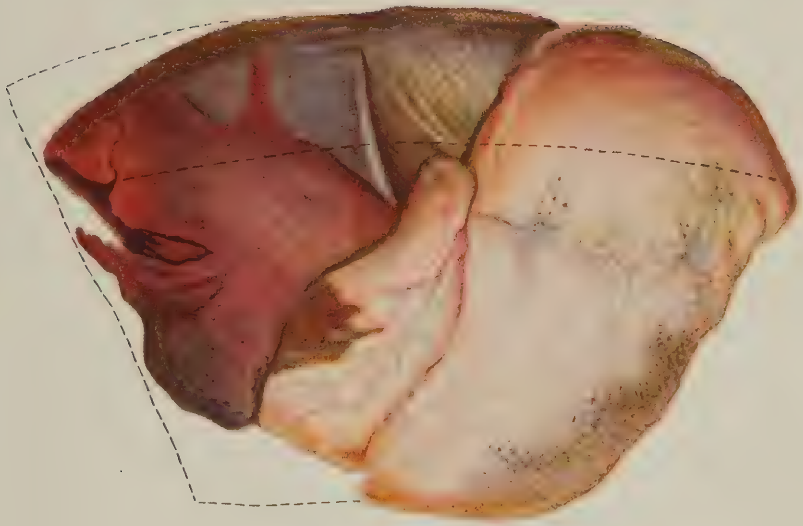
Lung tissue which is not obviously injured and which is nevertheless dangerous because of impaired circulation is characterized by limited inflation, collapse or compression, although intrapleural negative pressures are at least normal, or in spite of positive intratracheal pressures. Abnormal deflation, in the absence of reduced pulmonary elasticity, is due to the failure of either air or blood to enter the involved portion.

Massive contralateral collapse of the lung, noted occasionally with unilateral injury or disease, is attributable to spasm of bronchiolar musculature producing unilateral atelectasis or to a shunting of blood from the pulmonary artery of the sound side to that of the affected side, thus temporarily incoordinating the air cell capillary mechanism. The latter explanation, the shunting of the pulmonary arterial blood, is the more probable and can be traced to unusual responses to distortions in intrapleural pressures. Our experiments show that fluttering of the mediastinum, noted occasionally when thoracotomy is performed without differential pressure anesthesia, is due to sudden and rapidly repeated shunting of blood back and forth from one to the other lung. Neither of these complications occurs if positive pressure analgesia is used.

An atelectatic area of lung is airless because ingress of air is prevented and air previously present has been absorbed. Atelectatic lung after reinflation would have a normal circulation. Occasionally, and particularly after crushing parietal injuries, atelectasis is complicated by destruction of the blood supply and is in effect a traumatic anemic infarction, called carnification. Intratracheal positive pressure anesthesia makes a positive diagnosis of these lesions. Atelectatic lung, noninflatable, is overdangerous.

The more severe intrapulmonary lesions are well shown in a drawing (Plate V) of a right lung removed from a man who arrived dead at a field hospital. A jagged tangential wound was present in the inferior margin of the lower lobe. There was splenization of nearly the whole lobe. The middle lobe, except for one irregular area of hemorrhagic infiltration, and the entire upper lobe were emphysematous. The upper part of the lower lobe was atelectatic, brownish in color and carnified. Plate IV shows the effect of experimental pslenization. The marked fibrinous exudate upon the pleura over the area of hemorrhagic infiltration is proof of a defensive reaction. The limitation of

PLATE V



LACERATED WOUND OF LOWER LOBE OF LUNG. LOWER LOBE IS ALMOST ENTIRELY SPLENIZED; UPPER PORTION OF LOWER LOBE IS CARNIFIED; UPPER LOBE AND MIDDLE LOBES, EXCEPT FOR ONE AREA OF HEMORRHAGIC INFILTRATION, ARE EMPHYSEMATOUS

the exudate to the damaged lung is evidence that such lung is especially dangerous in the presence of infection.

Resection of a part of a lobe should be roughly pyramidal or wedge-shaped with the narrow aspect of the wedge toward the hilum, in order to remove only the parenchyma supplied by a bronchus and its associated vessels. It may be compared to cutting a dead branch out of a bush. Positive pressure makes this possible by clearly outlining the limits of normal lung.

Resection is difficult only when exposure is unsatisfactory. In the thoracotomy of necessity dislocation of a lung is difficult because these operations are usually done at a lower level and since the lung is generally less pliable because of more severe injury. Under these conditions some traction is unavoidable.

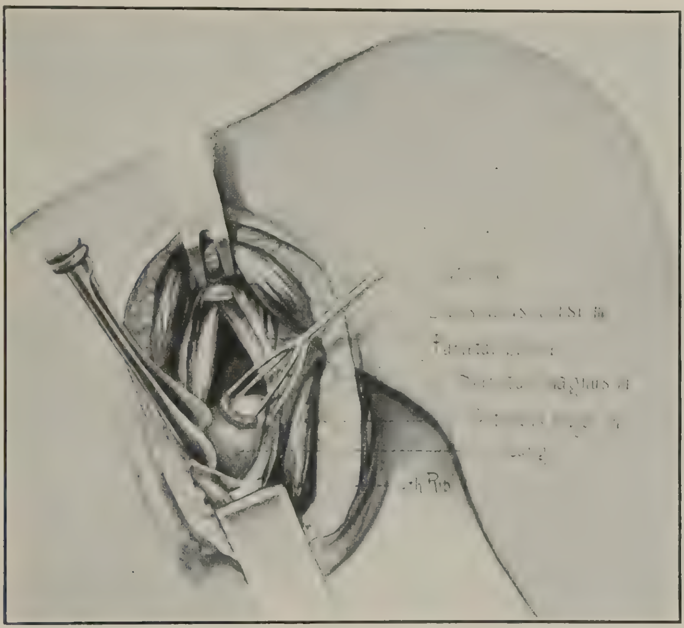


FIG. 191.—Thoracotomy of election. The margin of the deflated lung being guided toward the wound with Tuffier's forceps

It may be secured by a loop of gauze placed around the root of the lobe to be dislocated and caught with a clamp; or a pair of special forceps (fig. 186, *b*), like an enterostomy clamp, may be placed proximal to the margin to be removed and the resection carried out distal to the clamp. This is a makeshift procedure, but makes fairly accurate work possible.

Thoracotomy of election presents the most satisfactory exposure of the lung. After the chest has been opened as described above and the lung injuries have been determined, the lobes can be delivered into the wound for operation without traction. During deflation a free margin of a lobe is grasped gently with forceps of the Tuffier type (fig. 188, *b*) and guided toward the parietal opening. As the anesthetist increases the positive pressure this lobe follows the forceps into the wound (fig. 191). Manipulation with suitable variations in pressure allows the selection of the most satisfactory position for operation.

Little traction is required to maintain this position, which is preserved by the requisite inflation and the gauze packed between the lobe and the superficial wound.

A wedged-shaped resection is made through the margins of normal or relatively normal lung. Hot compresses to the cut surfaces check excessive bleeding while clamps are applied. Severed bronchi that can be seen or that provoke active bubbling must be secured. All branches of the bronchial artery spurting red blood under high pressure must be clamped. It is necessary to secure only the more actively bleeding branches of the pulmonary artery and but few branches of the pulmonary veins.

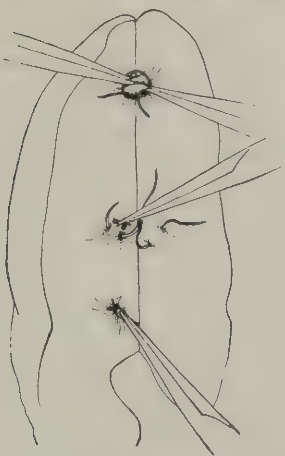


FIG. 192.—Methods of reducing the number of stitches used in repair after a resection. At the bottom is a simple ligature; in the middle, a suture on one surface is combined with a ligature on the opposite side; at the top, a double ligature is being made to serve as a suture

Pulmonary inflation makes possible the accurate clamping of these various structures, which would be difficult or impossible to find on the cut surfaces of a lung in deflation. Mass sutures inserted and tied while the lung is inflated would become too loose in deflation; if tied in deflation, they would be too tight during inflation. Consequently, multiple fine sutures must be used to approximate cut surfaces.

The number of sutures required may be reduced if the vessels which have to be tied are ligated in conjunction with a suture (fig. 192). The pleural repair should become an exaggerated serosa-to-serosa approximation as a safeguard against air leakage. A fine catgut stitch of the Cushing type introduced one-half inch from the margin of the incision accomplished this satisfactorily. Little puckering of the lung need result and only one knot should appear upon the pleural surface (fig. 193). When resection includes two surfaces of a lung it is easier to suture the dependent pleural layer first, when it can be done more rapidly and from the inside, and then to reconstruct the lung upon this plane.

Lung repaired by this method heals splendidly and with the minimum of scar tissue. Duval [24] states that the scar may be impossible of detection microscopically. There is in consequence little influence upon pulmonary elasticity. Vicious union is prevented so that the functional result is nearly perfect.

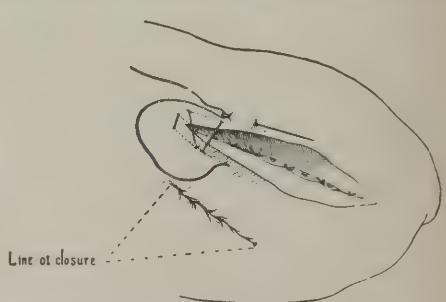


FIG. 193.—Closure of the visceral pleura with an exaggerated Cushing stitch

Complete lobectomy is indicated when an entire lobe is carnified. The possibilities of recovery are slight, not because of the operation but on account of the other serious injuries which are usually associated with military surgery because, aside from the injury, tissues are normal and individuals healthy. Crushing with forceps and ligation seem to be satisfactory if an ample flap covering is provided.

The unusual wounds of large bronchi should be sutured directly, and the suture line reinforced by a pleural graft to give additional protection against empyema from leakage.

OPERATIONS UPON THE HEART AND MEDIASTINUM

Early operations upon the heart and pericardium have been few because wounds affecting them are either promptly fatal or are treated expectantly. Such injuries as are disclosed by operation are easily remedied as they require little more than simple suturing.

Wounds of the mediastinum are always serious, particularly because of liability to infection. Bleeding from mediastinal vessels, even from the azygos veins, is not easily checked. Foreign bodies should be removed with the least traumatism and the resulting defect carefully repaired. Wounds of the thoracic duct have usually been fatal in spite of ligation.

OPERATIONS UPON THE DIAPHRAGM

When excisions are necessary they should be as limited as safety permits and adapted to spare the branches of the phrenic nerve. Usually all serious diaphragmatic injuries are well exposed by a thoracotomy of necessity. In the repair of defects of the diaphragm and in suturing it to parietal defects care should be taken to avoid including nerve branches in the sutures. Adhesions need not cause persistent immobility, but diaphragmatic immobility due to persistent paralysis commonly assures permanent adhesions.

When abdominothoracic injuries are suspected it is easier to attend to the chest injury first, as this operation is better tolerated and will establish more favorable conditions for laparotomy. Occasionally the entire abdominal repair can be completed through the diaphragm.

CLOSURE OF THE CHEST WALL

Next to positive pressure analgesia with nitrous oxide and oxygen, accurate closure of the chest wall, and particularly the repair of the parietal pleura, is the most important phase of the entire operation. No matter how excellent the rest of the care may be, a failure to obtain air-tight healing of the parietes results in an open pyothorax. The parietal pleura heals more rapidly than the more superficial tissues and offers greater resistance to the extension of inflammation either from within or without. Failure to secure smooth healing of this layer may lead to a persistent and severe empyema even though the more superficial wound heals firmly.

An illustration of the result of imperfect healing of the parietal pleura is found in Figure 194. The pleural sutures had caused tension necrosis so that separation occurred with exposure of the muscle and rib ends to the pleural cavity. This accident occurred in a dog but is exactly comparable to conditions seen repeatedly at human necropsies.

A well-controlled series of clinical and experimental observations show that smooth parietal healing is assured only when there is accurate pleural approximation in the absence of suture tension. A closure of this type is possible when the ribs next above and below the defect are brought abnormally close together.

The pleural approximation must extend beyond the rib ends at either angle of the incision in order to make certain that no denuded rib be exposed or become exposed within the pleural cavity.

The method of suture has been illustrated diagrammatically to show the steps in the closure of a thoracotomy of election. During the period of closure the anesthetist gradually increases the positive pressure to produce a slight degree of hyperinflation, so that when the parietal pleura is hermetically closed there shall be the least residual pneumothorax. Under these conditions approximately normal negative pressure is immediately reestablished.

Mattress sutures are preferable for reuniting the parietal pleura, and usually can be inserted through both margins of the cut periosteum, so as to gain double support (fig. 195). When this is impracticable the sutures should be placed far enough below the lower margin of the incision to avoid the intercostal vessels. Single mattress sutures are placed at each angle and in the middle of the incision. The spaces between these are closed with continuous mattress stitches. As indicated in the diagram the outer loop of each lateral stitch is inserted behind and lateral to the cut rib end. When the stitch is tied, pleural approximation external to the rib end is secured and the denuded rib excluded from the pleural cavity.

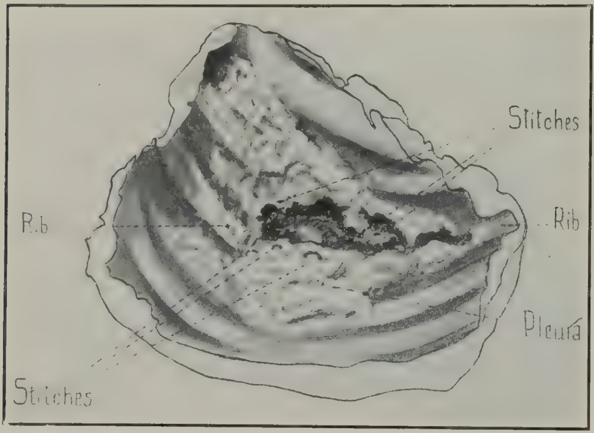


FIG. 194.—Inner aspect of the chest wall, obtained after death from purulent pleurisy without open pyothorax. Suture tension necrosis has permitted separation of the margins of the parietal pleura with exposure of the muscle and bone

An attempt to tie these sutures without overapproximation of the ribs next above and below results either in the stitches pulling out immediately or sloughing out later. The ribs are pulled together by means of a wire stay passed about them, as indicated in Figure 196, from which for the sake of clearness, the mattress sutures have been omitted. One loop is passed beneath the rib, and, if possible, kept outside of the pleura by hugging the rib with a needle, the point of which has been made slightly blunt. As this loop of the stitch crosses the pleural incision it takes in the margins of the parietal pleura and intercostal muscles to promote their subsequent apposition. The other loop is passed over the rib and does not include the intercostal structures.

When this wire stay is drawn taut the ribs are so approximated that it becomes possible to appose pleura to pleura without tension by drawing upon the mattress sutures. The three single stitches are tied (fig. 197); the continuous stitches are pulled tight, and tied at either end and in the middle to an end of a single stitch. This closure is air-tight if the suturing is done accurately. If there is a leak, it will be revealed by escaping air and must be corrected by a stitch or two to prevent subsequent production of tissue emphysema.

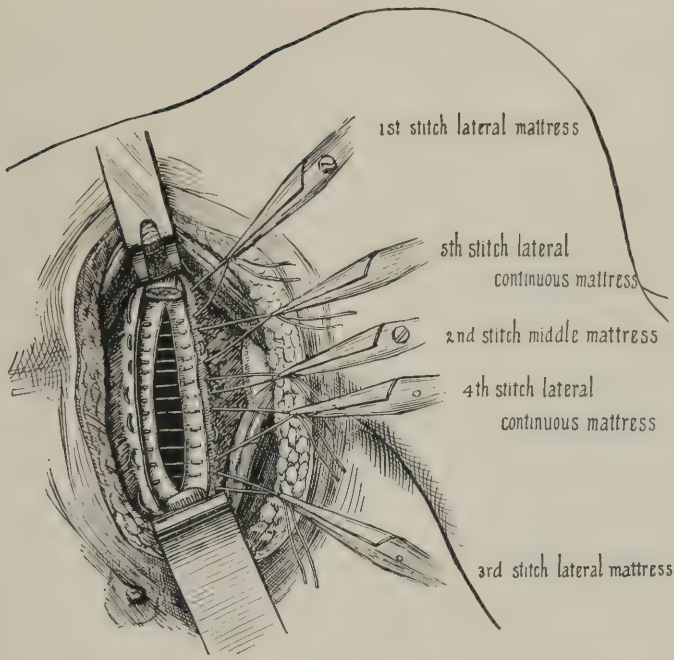


FIG. 195.—Closure of the chest wall after thoracotomy. Single and continuous mattress sutures are inserted through both periosteal margins on either side. The lateral sutures have the outer loop of the stitch placed beyond the rib ends

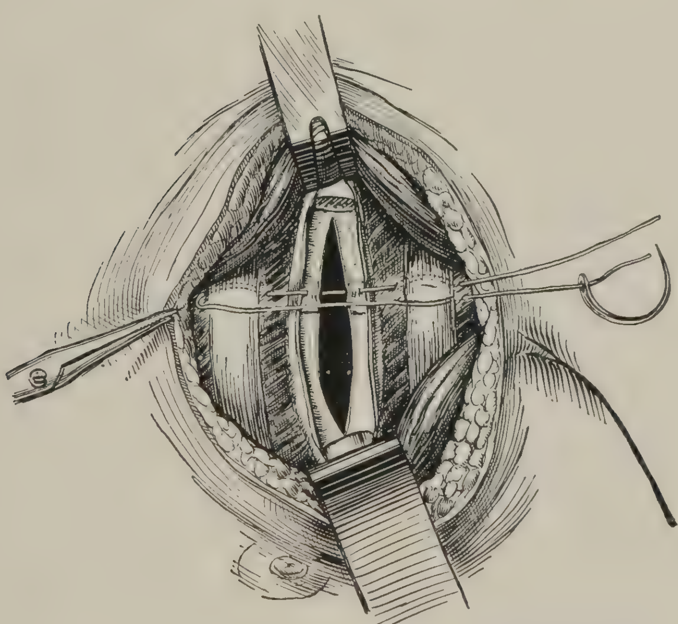


FIG. 196.—Closure of the chest wall after thoracotomy. In inserting a wire, rib stay, the posterior loop includes the periosteum, so as to aid in approximating the parietal pleura. The anterior loop does not penetrate the intercostal tissues.

Overapproximation of the ribs likewise secures an abundance of muscle tissue for the next layer. Healing is better if there is no dead space at the rib ends. A single suture, placed near the rib ends, as indicated in Figure 198, is tied and one end is cut. The other end is now tied to the end of the lateral mattress stitch in the parietal pleura. The tissues are thus held snugly over and against the end of the rib. The balance of this layer is closed with interrupted stitches, which promote better healing than continuous stitches.

The margins of the pectoralis and latissimus dorsi muscles are approximated with mattress sutures to safeguard the layer beneath from the dangers of suppuration in the subcutaneous fat (fig. 199). The deep layer of the superficial fascia is united by interrupted stitches (fig. 200), inserted opposite to the usual manner so that when tied the knot is not exposed superficially. The skin is closed with interrupted stitches to permit the escape of serum. Superficial drainage is often desirable to prevent tension. Small, soft drains suffice, and, removed within 24 hours, do not endanger infection of the deeper tissues.

Such exact methods can be criticized as time consuming and unnecessary. In a considerable proportion of all operations these objections are valid. However, there is another proportion, too large to be neglected, which can not always be recognized at the time of operation, in which they are invalid. We observed repeatedly that when details were neglected during periods of extraordinary activities, the subsequent healing was less satisfactory and led to distress and to death which greater care might have obviated. Need to serve greater numbers can and perhaps should justify compromises with the excellent rule that what is worth doing at all is worth doing well.

The wire rib stay is particularly undesirable, but absorbable sutures do not hold and silk or linen are unreliable. The wire should be removed in from four to six weeks as it will eventually cut through the ribs, and for this reason ought to be inserted so as to facilitate subsequent exposure of the twisted ends and removal through a small incision made with local anesthesia.

Methods of closing the chest in limited thoracotomy and in thoracotomy of necessity are based upon the same principles.

DRAINAGE

The use of primary and even of early drainage of pleural cavities after operation was generally condemned because open methods were employed, and because with them collapse of the lung is inevitable. Gray [38] cited figures to show that closure was safer than open drainage. The postoperative accumulation of serum was recognized as a constant occurrence, and routine aspiration, repeated as required, was adopted as a necessary precaution against its dangers. Lockwood and Nixon [23] found that interrupted drainage by aspiration reduced the need for subsequent rib resection and open drainage.

Experience in the early and late treatment of pleurisy shows that air-tight insertion of drainage tubes provided with some device to prevent the entrance of air is the most satisfactory procedure, and that the earlier such drainage is established the better the results. It is evident from the writings of Elliott and Henry,[16] Dobson,[39] Mozingo,[40] Blankenhorn,[41] Whittemore,[42] McKenna,[43]

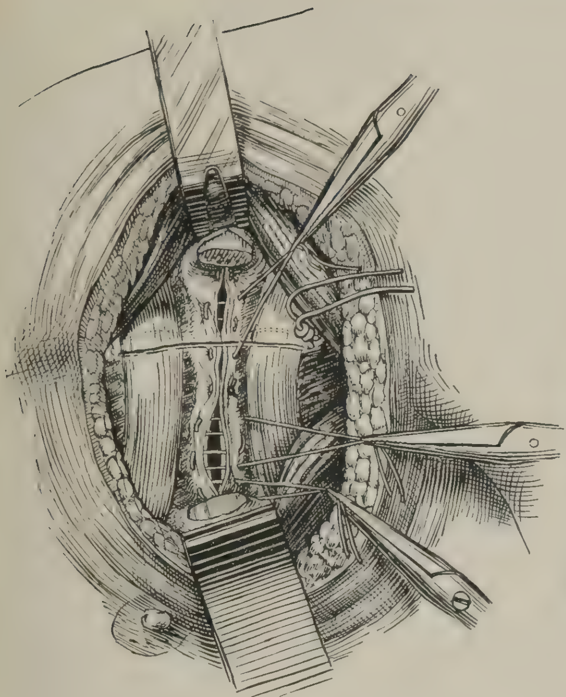


FIG. 197.—Closure of the chest wall after thoracotomy. The rib stay is drawn taut and fixed so that it can easily be removed

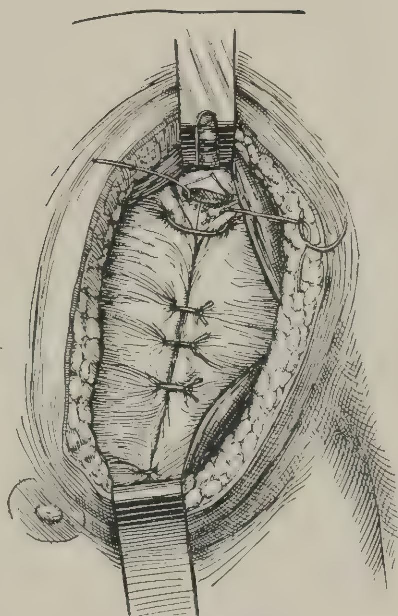


FIG. 198.—Closure of the chest wall after thoracotomy. The layer of fat and muscle is closed over the defect caused by rib resection

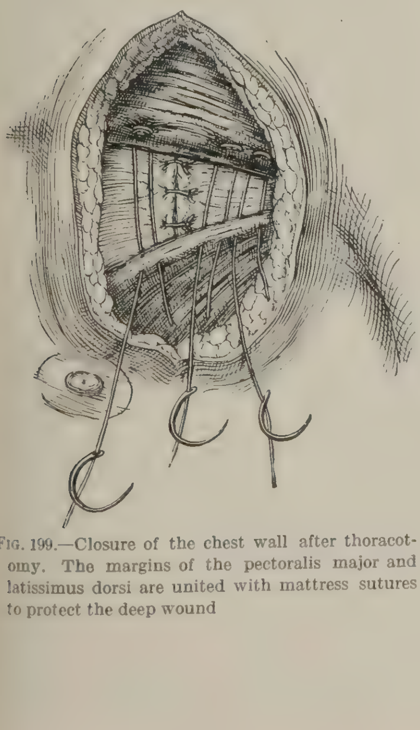


FIG. 199.—Closure of the chest wall after thoracotomy. The margins of the pectoralis major and latissimus dorsi are united with mattress sutures to protect the deep wound

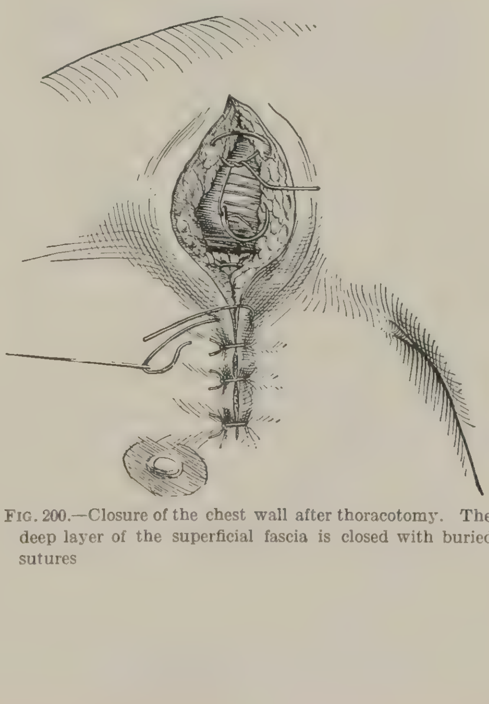


FIG. 200.—Closure of the chest wall after thoracotomy. The deep layer of the superficial fascia is closed with buried sutures

and Roberts [44] and from our own experiences, that a catheter drain inserted intercostally by trocar and cannula, and provided with an automatic one-way check valve, is the method of choice. (Fig. 201.) By this means negative pressure can be maintained until full inflation is secured. Employment of fluctuations in intrathoracic pressure to provide the expulsive force is better than using suction, as it is in keeping with normal physiologic movements. It is also very much simpler, and, being automatic, is not dependent upon constant attention for its success.

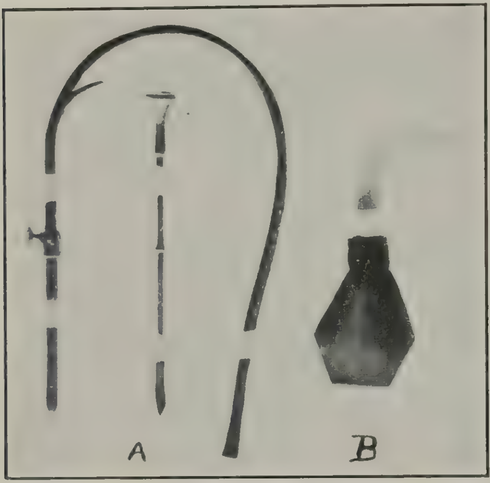


FIG. 201.—A, Trocar, cannula, and catheter for intercostal drainage: B, flap valve used to secure automatic oneway drainage

Duval [24] advised against operating more than 30 hours after injury. The dangers of empyema after that time are very great but are less with operation than without, especially if primary drainage is used. We found that early operation, conducted by methods described above, gave a mortality rate of 4 per cent in an unselected consecutive series of thoracotomies performed within eight hours and the men had not been chilled. When the operation was delayed beyond 24 hours or the wounded were cold or wet, the mortality rate was increased tenfold. It seems now that had primary drainage been used more as a routine many of these lives could have been saved. It is certain that primary drainage after operation for the large wounds with open thorax, foreign bodies, and lacerations of liver and diaphragm was effective in limiting disastrous pleurisy.

POSTOPERATIVE TREATMENT

The use of positive pressure anesthesia is the most important factor in simplifying the postoperative care, because of the decreased distress due to the abolition of pneumothorax, the better general condition of the patient, and the elimination of complications.

Morphine in generous doses is useful in reducing pain, in limiting the rate of respiration, and in controlling coughing. The value of posture has been overrated. Patients naturally take the most comfortable position. Other things being equal lying upon the sound side is preferable.

The chief interest is in the postoperative effusions. If primary drainage has been instituted there is only need to see that the tube is free. If the chest has been closed tight one of two courses is open: Either aspiration should be done the second day and repeated often enough to prevent any considerable reaccumulation, or it should be done when signs of pressure or of infection develop, or when absorption is unduly delayed. There are objections to all methods, least of all to primary drainage.

The most important feature, next to safeguarding life, is the earliest reestablishment of full pulmonary functions. No breathing exercises should

begin until the patient is afebrile, and then if a rise in temperature should follow they must cease until the temperature is again normal. Holding the breath, slow breathing, and blowing against pressure are valuable, with particular attention given to abdominal breathing in order to reactivate the diaphragm. Patients should be encouraged to get out of bed as early as safety permits and to exercise the muscles of the thorax. Recovery is protracted as early activity is delayed. Active duty within six weeks of an injury serious enough to require resection of part of a lower lobe was achieved by one soldier, and this indicates the possibilities of treatment.

COMPLICATIONS

Pleurisy is to be regarded as a natural and constant sequel of an intrathoracic injury, including thoracotomy. Empyema is the commonest and most significant complication. There is no sharp line separating the two and none should be assumed. The best treatment of empyema is to limit the initial pleurisy, and this is more certainly accomplished by primary drainage than by any other method. When primary drainage or routine aspiration is impossible exploratory puncture is indicated by signs of sepsis or by signs of a sudden increase in the exudate. The probability of subsequent development of an empyema can be established by the soiling and reaction of the pleura present at the time of operation, and by the length of time elapsing between injury and operation. As a rule, the more virulent the infection the more rapid the development of postoperative empyema and the less the likelihood of limiting adhesions being formed.

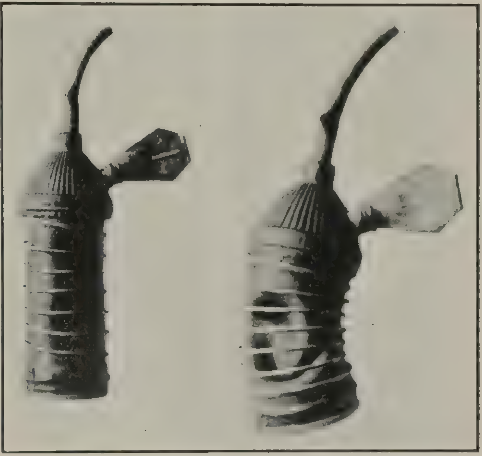


FIG. 202.—Form of trap to be attached to a catheter drain. It provides both a receptacle for the discharge and a flap valve. If slight suction is needed, it can be provided by collapsing the trap

Open operation for empyema performed without differential pressure is dangerous if done before adhesions form, and may be futile if delayed. Catheter drainage should be the first resort and will usually be sufficient. If more radical intervention is required thoracotomy with positive pressure analgesia will permit of all necessary manipulations without the dangers of pulmonary deflation, and with the least danger of disseminating infection. The wound may be closed completely, and tube or catheter drainage established elsewhere, or a tube may be sewed in hermetically at an angle of the incision. It is understood that some form of valve is provided so that subsequent irrigations may be given without permitting air to enter the chest. Slight constant suction will often prevent coagulation of serum within a catheter. This suction and a receptacle to catch the discharge may be provided by a simple apparatus (fig. 202). Fluoroscopic control makes it easy to insert the catheter accurately and safely.

Pneumonia is usually contralateral and of the bronchial type. It is rare, as is contralateral pleurisy, when gas-oxygen pressure analgesia is used. The probable explanation is the less urgent dyspnea and consequent failure of aspiration of blood and mucus which are expelled from the bronchi of the injured side into the bronchi of the sound side.

Contralateral collapse, which has been so well described by Bradford,[19] does not occur when positive pressure is used.

The presence of a foreign body may prove a serious handicap to permanent recovery. It has been said that every man harboring one foreign body suffers from two, one physical and one mental. Small shell fragments and bullets embedded in the lung may cause pain and dyspnea because they are sources of chronic traumatism, and because their removal is occasionally curative. The distress is more often due to the effects of pleurisy, restricted motion of the parietes, reduced intrapleural negative pressure, or to impaired motion of the diaphragm. Under such conditions the foreign body is an incident and its removal can change the mental attitude only. The indications for removing these intrapulmonary foreign bodies are a matter of opinion.

Three methods are available for the late removal of intrapulmonary foreign bodies: First, the use of forceps of the alligator type introduced intercostally and manipulated under fluoroscopic control. Petit de la Villeon[45] introduced this procedure and reported remarkable results. Its dangers, particularly when the foreign body is at the root of the lung, are obvious. It is a blind procedure. A second method, also a compromise, consists in a short costectomy, suture of the parietal to the visceral pleura, and removal of the foreign body with forceps guided by a Hirtz compass. Like the method first described, this method is useful in the extraction of small superficial fragments which are of the least significance. When the foreign bodies are deeply placed, near the large vessels or mediastinum, an open operation should be done, the foreign body removed and the incidental damage accurately repaired. The best treatment would have been removal of the missile at the time of injury.

Foreign bodies in the pericardium, in the heart muscle, and in the cavities of the heart have been removed. Aside from the possibilities of civil surgery suggested by these highly dramatic operations a very practical hint has been given toward selecting the method of approach. Most operators have attempted to keep out of the pleural cavity and have generally succeeded in provoking an empyema. An open operation, such as a thoracotomy of election, if done with differential pressure, gives a very satisfactory cardiac exposure, and would make possible better surgery and smoother recoveries.

Late, persistent, or recurrent empyema suggests the possibility of some chronic irritant like a foreign body or a costal osteomyelitis, both of which must be excluded with the least possible delay. Much has been and will be written about methods of treating open pyothorax, and various methods of irrigation and decortication. All have one object, to convert an open into a closed thorax by pulmonary inflation. The essential factor is the reapposition of visceral and parietal pleura, whether attained operatively as proposed by Roux-Berger[46] or by breathing exercises. The general plan of procedure is

based upon the elimination of infection and reduction of irritation: solutions which favor disintegration of fibrin are indicated. To date nothing superior to Dakin's solution has been found.

Treatment of closed pyothorax is being advanced by the application of principles established by Bowditch.[7] Instead of an immediate costectomy and the formation of an open pyothorax it is far better to introduce one or two catheters by means of a trocar and cannula. Intermittent irrigation and continuous drainage, which protect and increase pulmonary inflation, may lead to prompt recovery. If this method be partially unsuccessful, a less forbidding operation is ultimately required. Encapsulated pockets may be tapped safely if the manipulations are done with the aid of a fluoroscope. The best treatment of empyema is that proposed by Roux-Berger,[46] early and complete operation after injury.

Reports by Rist, Flandrin, Bernard, Sommerville, and others,[47] Pehu and Daguet,[48] all show that chest wounds are unlikely to favor early development of tuberculosis. Tuffier[30] noted that the disease is prone to appear on the opposite side. The reasons are clear. The injured side is apt to be incompletely expanded and is in a condition, according to Cloetta,[36] to offer hypernormal resistance. The opposite side, constantly affected by compensatory emphysema, is in a state of reduced resistance.

Physical disability will persist in the wounded in proportion to the interference with the respiration and circulation. The interference may be so slight as merely to reduce the powers of compensation and become apparent only under stress, or it may cause dyspnea, palpitation and cyanosis with slight exertion. If there is incapacity, attempts should be made to determine the cause, and such treatment, operative, medical, or physical, be employed as will improve function. It is easy to make a diagnosis of neurosis or malingering in individuals who have sustained chest injuries, and do them a grave injustice. Complete physical examination before and after exertion, controlled with a fluoroscope, and proper blood pressure determinations, will generally disclose reasons for the complaints of pain and disability.

RÉSUMÉ OF THE RECORDS OF THE WOUNDED

An analysis of the histories of patients has been made to disclose the causes of deaths and of the extent and duration of disabilities in those who survived in order to determine if possible all the factors which might influence more effective care of thoracic injuries.

The relative merits of divers methods may be judged from two aspects—immediate military necessities imposed by fighting conditions, and the welfare of the individual which must always be second to winning wars. However, in a protracted struggle success is determined by the morale and strength of an army, both of which depend to a great extent upon each soldier being assured the utmost consideration before and after he is hurt. Hence, there is no reason to consider other procedures than those offering individuals the largest opportunities for undelayed recoveries.

There are several sources of error in the data presented from which deductions must be made. Our records are incomplete; observers may have been biased; and there is a natural disposition on the part of the disabled to magnify

their misfortunes, particularly when financial compensation varies with the extent of disability. On the contrary, the details that can be established suffice to indicate the facts essential to drawing conclusions. The causes of death are usually easy to recognize. The causes of disabilities are unmistakable, viz., reduced motion of the parietes, particularly of the diaphragm; diminished elasticity of lung; abnormal intrapleural pressures, and myocardial deficiencies. Not only are these lesions demonstrable, but vital capacity also may be used as a check upon the extent of their composite detriments because it measures the extent of disabilities attributable to cardiorespiratory diseases.

METHODS

Attempts were made to keep notes upon each wounded man, to take photographs that would show the nature of wounds and postoperative conditions, to make routine post-mortem examinations, to trace survivors after they were evacuated from forward hospitals, and finally to ascertain the nature of their ultimate disabilities.

Some patients were treated and no notes were kept; some notes were lost. But it is improbable that these breaks in our records (not above 25 per cent) are of material significance, since enough information is available to give a dependable average. Unfortunately the photographic and X-ray films were stolen from the central laboratory at Dijon. They would have shown details that can not now be described. It was impossible to trace the wounded in France, so there was no control of their later and most important postoperative treatment. It has since developed that except for necessary surgical care they got none. Although unfortunate for the individuals, this neglect is of great value in demonstrating the limitations of operative procedures alone as means to restoration of function.

Through the intercessions of the Surgeon General of the Army and the generous cooperation of the United States Public Health Service a member of the unit was enabled in 1921 to visit a number of patients in Government hospitals who had had chest wounds and to see certain others living near by who came in voluntarily for examination. This officer secured sufficient accurate information to determine the extent, nature, and causes of disabilities in those whom he examined and to make it possible to estimate dependably the conditions of others not examined but whose records could be found. Here again, although our records are incomplete, it is probable that enough has been learned to give a reliable average of results, since the more seriously incapacitated were hospitalized, and they form a larger part of the observations.

The series here recorded consists of 104 patients whose records are available. They have been divided into four groups, according to the nature of the first operation performed: (1) Excision of parietal wound; (2) limited thoracotomy; (3) thoracotomy of necessity; and (4) thoracotomy of election.

The history of each patient is outlined, the cause of death presented, or the nature and causes of disabilities stated. The treatment of each patient is criticized. Similarly, the treatment of each group is criticized. Finally, reasons are given to show how the entire series could have received better care from the time injuries were inflicted until the final results were established.

GROUP I. EXCISION OF PARIETAL WOUND

1. W. M. July 22, 1918: Bullet, perforating wound, left chest. Entrance below and mesial to angle of right scapula; thence through tissues of back, through left chest, to lodge in left side of neck. Duration, unknown. Hemopneumothorax moderate. Condition good (?). Operation: Excision of parietal wound. Removal of foreign body. Pleural wound not exposed. Closure without drainage. July 24, 1918: Fluid not increased; partial pneumothorax persists. Evacuated in good condition. Returned to duty in three months. 1921: Records available. Disability less than 10 per cent and due to chronic pleuritis.

Recovery would have been more certain, rapid, and complete had hemothorax been removed and lung sutured at time of operation.

W. B. July 27, 1918: Bullet, through-and-through, sucking wound, left chest. Entrance, posterior triangle above left clavicle; exit, in fourth interspace, lateral to midclavicular line. Hemopneumothorax; heart slightly displaced to right. Condition good (?). Duration, unknown. Operation: No rib injuries recognized. Wounds excised and closed without drainage. Hemothorax not aspirated. Pressure anesthesia disclosed no air leakage. August 1, 1918: Uneventful recovery. Healing smooth. Left lung slightly cloudy. Left diaphragm excursions reduced one-half. Right chest clear. Estimated disability less than 10 per cent and due to pleuritis.

Hemothorax should have been aspirated at time of operation and again later if persistent. Absence of rib injuries and of air leakage contraindicated thoracotomy.

3. D. C. July 27, 1918: Bullet, penetrating wound, left chest. Entrance, upper anterior aspect of chest; lodgment, just to left of aortic arch; moves with respiration, probably intrapulmonary. Moderate hemopneumothorax; heart displaced to right. Duration, six hours. Condition good (?). Operation: Entrance wound excised. Pleural wound not found. No rib injuries. No air leakage recognized. Closure with one gutta-percha drain. Hemothorax not aspirated. July 31, 1918: Smooth convalescence. Both sides of chest cloudy; left more so. Left diaphragm moves, though but slightly. Foreign body at root of left lung. Tissue emphysema. Early removal of drain showed that drainage of superficial tissues can be helpful and harmless. August 2, 1918: Evacuated in good condition. Estimated disability less than 10 per cent and due to pleuritis.

Perforation in pleura should have been located and accurately closed with muscle to prevent emphysema. Hemothorax should have been aspirated. Removal of foreign body not indicated.

4. E. L. D. July 28, 1918: Shell fragment, penetrating wound, left chest. Entrance through left scapula; lodgment in left lung, where foreign body 1 cm. in diameter can be seen to move with respiration. Hemopneumothorax moderate. Duration, 24 hours. Condition, poor. Operation: Gutter wound, left arm, excised. Wound through left scapula excised and drained, as patient's condition did not permit of thoracotomy. Gum acacia given before and during operation. August 3, 1918: Smooth recovery. Pleuritic exudate still present and heart displaced to right. Evacuated in good condition. Disability, estimated at less than 10 per cent, as this man returned to active duty, can be attributed to pleuritis.

No radical operation was possible under the conditions. Aspiration of hemothorax should have been done.

5. R. E. H. July 30, 1918: Shell fragment, perforating wound, left chest. Entrance second left interspace, midclavicular line; lodgment beneath skin of back at eighth interspace. Massive hemothorax; heart much displaced to right. Duration, 30 hours. Patient treated $6\frac{3}{4}$ hours because of shock. Gum salt intravenously raised systolic blood pressure 30 mm. and made operation feasible. Operation: Excision of both entrance and exit wounds with removal of foreign body. No rib damage. Positive-pressure analgesia forced out part of hemothorax, which was not aspirated. No air leakage from lung recognized.

Pleural openings closed with muscle. Wounds closed without drainage. August 3, 1918: Convalescence and healing smooth. Pleuritic exudate subsiding, but heart still displaced to right. Evacuated in good condition. July 20, 1921: Passed through several hospitals in France. No further treatment. Discharged from service March 7, 1919. Disability, 10 per cent. Dyspnea on extraordinary exertion. Unable to lift heavy weight. Limited expansion at left base. X-ray shows chronic pleuritis; adhesions between left diaphragm and ninth rib and little mobility of diaphragm. Heart competent. Vital capacity, 71 per cent.

Disability due to pleuritis. Rating at 10 per cent is seemingly too low in view of vital capacity. Conditions at time of operation prevented more radical treatment. Aspirations should have been performed; possibly one-way catheter drainage. Systematic breathing exercises would have reduced disability to less than 10 per cent. Limited thoracotomy might have been employed.

6. J. F. M. July 31, 1918: Shell fragment, penetrating wound, right chest. Entrance above and mesial to spine of scapula. Large hemothorax; heart displaced to left; foreign body one cm. in diameter in lung hilum close to aorta. Duration and condition not noted. Operation: Entrance wound excised. No rib injuries. Hole in pleura plugged with muscle. Superficial wound drained with gutta percha. August 1, 1918: Toxic and uncomfortable. Pleural effusion increased; heart displaced to left anterior axillary line; 500 c. c. bloody fluid aspirated. Immediate relief. August 3, 1918: Condition good. Fluid not reaccumulating. Evacuated. July 30, 1921: A second aspiration was subsequently performed at a base hospital in France. Returned to United States September 15, 1918. No further treatment. Disability rating 20 per cent. Dyspnea on slight exertion. Chronic cough. Fibrous pleuritis right side, marked above. Diaphragm deformed and movements restricted. Peribronchial thickening right side. Foreign body in lung in front and lateral to aorta. Myocardium slightly defective. Vital capacity 63 per cent.

Disability due to pleuritis, pulmonary sclerosis, and myocardial deficiency. Unable to follow active occupation. Disability rating of 20 per cent is apparently low. More radical operation and removal of foreign body had man's condition permitted would have been wiser. Man states he had suffered from dysentery for two days preceding injury so his condition may have been unfavorable. Immediate aspiration, perhaps catheter drainage, should have been used. Subsequent breathing exercises could have reduced disability.

7. F. J. S. August 10, 1918: Shell fragment, through-and-through wound, right chest. Entrance to left of spine at level of angle of scapula, thence through vertebræ and ribs upward and to right to exit through posterior triangle of neck, fracturing first rib. Duration 21 hours. Condition critical. Operation: Entrance and exit wounds excised. Pleural defects plugged with muscle and superficial wounds sutured; 500 c. c. of gum salt given intravenously during operation raised pressures from 98/60 to 108/64. Soon after operation pressures had fallen to 60/30. Transfused 500 c. c. citrated blood. Pressures raised to 100/60, temporarily. Death within a few hours. Necropsy: Kissing wound at apex of right lung. Splenization right upper lobe. Moderate hemothorax. Dilatation of right heart.

This man could have recovered had it been possible to operate when he was in good condition. Removal of right upper lobe would have been necessary. An illustration of the need to protect the pulmonary circulation.

8. N. E. L. September 12, 1918: Shell fragment, penetrating, right chest. Entrance wound at tip of right clavicle. Moderate hemothorax. Foreign body 1.8 cm. in diameter within lung. Cough and hemoptysis marked. Duration five hours. Condition good. Operation: Entrance wound and tract excised. No rib damage. Entrance into pleura not found. Superficial drainage. No aspiration. September 14, 1918: Healing smooth. Pleuritic effusion reducing. Heart no longer displaced to left. Evacuated in good condition. 1921. Records available. Disability less than 10 per cent.

Immediate aspiration should have been performed.

9. W. J. McC. September 12, 1918: Shell fragment, penetrating wound, right chest wall. Entrance in third interspace at right sternal margin to lodge beneath skin over fifth rib in anterior axillary line. Small hemothorax; heart not displaced. Some hemoptysis. Duration unknown. Condition good. Operation: Excision of wound of entrance; resection of upper right margin of sternum and of fractured third rib. Pectoralis major muscle split for exposure. Foreign body 2 cm. in diameter removed. Pleura not opened. No suture closure. Gutta-percha drain. September 17, 1918: One aspiration removed straw-colored serofibrinous fluid. X ray shows some cloudiness at right base. Diaphragm and its excursions normal. December 24, 1918: Returned to active duty. August 3, 1921: Little disability. No cough. Rating 10 per cent. Heart normal. In lungs there is slight increase in peribronchial striæ; otherwise normal, as is the diaphragm. Basal chronic pleuritis, right. Vital capacity, 90 per cent.

Disability is due to pleuritis which could have been eliminated with aspiration at time of operation and subsequent breathing exercises. This is an example of pulmonary injury caused probably by indirect violence. In this instance thoracotomy was not indicated as it would have been had there been splenization of the lung.

10. F. K. September 12, 1918: Bullet, through-and-through wound, left chest wall. Entrance at anterior axillary line, level of fourth rib; exit at posterior axillary fold at level of sixth rib. Small hemothorax; dyspnea. Duration seven hours. Condition good. Operation: Wounds of entrance and exit excised; connecting tract laid open and excised. No rib injury nor pleural laceration. Superficial wound closed with drainage. September 18, 1918: Pleuritic effusion persists in small amount, but is decreasing. Evacuated in good condition. No further records. Estimated disability less than 10 per cent.

Aspiration, perhaps repeated, should have been employed.

11. P. O. September 26, 1918: Bullet, through-and-through wound, right chest wall. Entrance just below right sternoclavicular joint; exit below and external to right nipple. Small hemothorax. No dense shadows. Duration five hours. Condition fair. Operation: Ten and a half hours later. Wounds of entrance and exit resected; connecting tract opened. No rib or pleural damage. Lacerated outer one-half of pectoral muscle removed. Partial closure. Superficial drain. September 30, 1918: Condition excellent. No increase in pleuritic effusion. Evacuated. No further records. Estimated thoracic disability zero.

Aspiration, especially if performed under fluoroscopic control, would have been wiser.

12. E. L. October 1, 1918: Bullet, through-and-through wound, neck and right chest. Entrance above inner third clavicle; exit, right axilla, level of fifth rib. Cold, exhausted; pulse feeble and rapid. Extreme interstitial emphysema of face, neck, arms, and thorax. Grunting dyspnea. Exhaustion due to long, hard ride. Duration 12 hours plus (?). Operation: Excision of entrance wound. Air escaped from tissues in bubbles. Wound packed with gauze and a tube drain inserted. Condition prevented further intervention. Death 14 hours later. Necropsy: Left pleural cavity, negative pressures persist. Right pleural cavity, positive pressure; lung compressed and diaphragm depressed by large hemopneumothorax. Through-and-through wounds of trachea in episternal notch and of left upper lobe. Peritracheal emphysema; trachea not obstructed. Death due to obstruction of venous return from head.

This man arrived too exhausted to stand operation. If he had been received earlier tracheal repair or tracheotomy would have been effective.

13. R. M. October 13, 1918: Shell fragment, through-and-through wound, left chest wall. Entrance beneath anterior axillary fold; exit below angle of scapula. Much bone

damage. Small hemothorax. Condition good. Duration 22 hours. Operation: Entrance and exit wounds excised. No pleural injury. Wide resection of scapula. October 19, 1918: Evacuated in excellent condition. No further records. Estimated thoracic disability zero.

Even this limited hemothorax should have been aspirated.

14. W. J. W. October 14, 1918: Shell fragment, penetrating, right chest wall. Entrance wound right axilla, level of fifth rib. Foreign body, 0.3 by 0.7 cm., beneath right nipple. Operation: Entire wound excised. Foreign body removed. No rib or pleural injury. Partial closure. October 16, 1918: Wound clean. No abnormal chest findings. Excellent condition. Evacuated. No further records. Estimated thoracic disability zero.

15. G. S. October 14, 1918: Shell fragment, penetrating wound, left chest. Entrance just below spine, left scapula. Moderate hemothorax. Foreign body 0.6 by 0.8 cm. in lung. Intrapulmonary hemorrhage. Duration, nine hours. Condition, fair. Operation: Two and a half hours later. Wound of entrance excised. Fractured scapula resected. Pleural defect closed with muscle. Partial closure. October 15, 1918: Comfortable. Stations changed. No further records.

If this man's condition had permitted, a thoracotomy of election should have been performed, as it would have caused less risk than a splenized lung.

16. B. W. November 1, 1918: Shell fragments, 0.5 by 0.8 cm., and 0.5 by 0.12 cm., penetrating wounds of back and right chest. Sucking wound at entrance at ninth rib below angle of right scapula. Small hemopneumothorax. Heart displaced to left. Complete section of cord. Duration, 24 hours. Condition, poor. Operation: Wound of entrance excised. Contused muscle, broken ribs, and vertebræ resected. Closure with muscle flaps. Superficial drainage. Died within six hours. No necropsy.

Lethal injury. Treatment with morphine would have been wiser.

17. H. G. H. November 2, 1918: Shell fragments, penetrating; seven wounds of back and right chest. Moderate hemothorax; hemoptysis. Duration, six hours. Condition, poor. Operation: One and a half hours after admission. Multiple wounds excised and superficial foreign bodies removed. Fractured spinous processes resected. Wound in pleura closed. November 18, 1918: Condition, fair. Fluid in chest despite previous aspiration. No pneumothorax. Febrile. Died some days after evacuation. No further notes.

This man's life might have been saved by proper drainage, as he died presumably from emphysema.

18. H. C. H. November 12, 1918: Bullet through-and-through wound, right chest. Entrance over third rib, right parasternal line; exit, right posterior axillary line at level of fifth rib. No hemoptysis. Moderate hemopneumothorax and cardiac displacement. Some tissue emphysema. Duration, 34 hours. Condition, fair. Operation: Exit wound excised. Slight sucking. No rib injury. Closure with superficial gutta percha drain. Entrance wound excised. No rib injury. Closed. Chest aspirated. November 16, 1918: Temperature normal. No cardiac displacement. Small pleuritic effusion. Condition, excellent. Evacuated. February 5, 1919: Discharged from service. No further treatment. August 12, 1921: Dyspnea on slight exertion. No cough. No limitation in respiratory excursions. Slight fibrosis at right apex. Diaphragm free. Heart: Rapid action; otherwise normal. Vital capacity, 110 per cent. Disability rating, 25 per cent.

Disability granted is due to cardiac excitability and not to previous injury. This man's treatment, in view of the duration of injury before operation, has been justified by the results. An intercostal catheter drain might have done harm and accomplished no more good.

SUMMARY OF GROUP I

The number (18) treated by extrapleural excision is 20 per cent of the entire series. It would have been much larger had not so many of the less seriously wounded been sent to hospitals farther away.

Fatalities.—There were four deaths (22 per cent). Two (7, 12), lethally affected at time of operation, could have recovered if operated upon earlier. One (16) was fatally injured because of a cord lesion; one (17), despite multiple injuries, might have recovered had the principles of primary drainage been understood and suitable apparatus been available. One (17) was operated six hours after injury; the others after 24 hours. No death can be attributed to the operation itself. One is chargeable to surgical error, the failure to provide drainage. This gives a surgical mortality of 5 per cent.

Disabilities.—The ultimate disabilities of 13 of the 14 who recovered are quoted from allowances made by the War Risk Insurance board or by estimates made in comparison therewith. Three (11, 13, 14) recovered without disability from thoracic lesions. Five (1, 2, 3, 4, 10) had disabilities of less than 10 per cent. Two (5, 9) had ratings of 10 per cent. One (6) was rated at 20 per cent and one (18) at 25 per cent. The ratings of two (5, 6) are low and the rating of one (18) is high. The result in one (15) can not be surmised. A generous estimate of the average disabilities for this group is 10 per cent. The average interval before return to duty was about 90 days. Pleuritis, arising from hemothorax, caused the disabilities in all but one (18, disordered action of the heart). In four, hemothorax was caused by transmitted violence as the parietal pleura had not been punctured. Three of these (11, 13, 14) recovered without disability, and in the fourth (10) it was less than 10 per cent. On the average 24 hours had elapsed between receipt of injury and operation.

Had it been possible to have hospitals close to the zones of conflict or to have had effective sifting of the wounded and expeditious transportation, the mortality rate would have been less. Had the proper use of intercostal catheter drains been understood or had the members of this unit been permitted to give patients individual postoperative attention, particularly in earlier and perhaps repeated aspirations, the disability rate (10 per cent) would have been reduced. Also had continued after-care, especially breathing exercises, been a routine, the average duration of disabilities (90 days) would have been less.

DEDUCTIONS

Virtually all wounds of the chest should be treated by prompt excisions of injured extrapleural tissues, which without adding to immediate dangers give protection against inflammation in parietal tissues that can cause pyothorax and frequently reveal unsuspected deeper lesions demanding more radical operation.

Parietal excisions should be performed under positive pressure gas analgesia, because these minor operations can thus be more rapidly and safely conducted. Discomforts are less than when local anesthesia is employed; there is less likelihood of spreading infections and the exposure of a sucking wound is not accompanied by pulmonary collapse. Administration of ether by open methods is unwarranted.

Aspirations or suitable drainage of hemothorax should be almost routinely employed with parietal excisions to reduce pleuritis and be followed by systematic exercises to minimize the effects of pleuritis. This combination assures the most complete, undelayed recoveries.

CONCLUSIONS

The chief objections to routine parietal excision have been: (*a*) It increases immediate dangers; (*b*) it is too time-consuming, especially during periods of active fighting when simple aspiration with or without air replacement suffices; (*c*) it overburdens the forward hospitals and nurses.

(*a*) Immediate dangers are not increased and ultimate dangers are reduced. (*b*) Less time and attention are required to obtain healing if wounds receive prompt attention. Reasons have been given to show why simple aspiration is inadequate and ofttimes dangerous in spite of the many excellent recoveries that may be secured. Air replacement is unsound therapy. Its one excuse is to stop hemorrhage from lacerated lung and can only be effective by producing pulmonary compression. Not only is pulmonary compression undesirable from every standpoint, but also it must be controlled by manometric determinations which are time-consuming. (*c*) Virtually all wounds must be given some attention and all but those receiving trivial injuries must be hospitalized. Hospital facilities of an army have physical limitations which can be increased only by reducing the durations of disabilities. When the numbers of severely wounded overtax forward hospitals, those suffering from less severe chest wounds can be sent as far back as they can be delivered within 24 hours while still in good condition. This plan in the long run would be more effective than the giving of makeshift early treatment that assures more prolonged and less complete recoveries. Parietal excisions, with and without immediate aspiration or primary drainage, are applicable to the least severe chest wounds or to those in such critical condition that no further intervention may be attempted.

GROUP II. LIMITED THORACOTOMY

1. E. B. July 20, 1918: Bullet, through-and-through wound, both sides of chest. Entrance at left nipple; exit above right nipple. No physical signs of intrapleural involvement. No X-ray examination. Duration nine hours. Condition (?). Operation: Entrance and exit wounds excised and connected. Fractured ribs and sternum resected. Wounds in lung sutured and in pleura closed with muscle. No aspiration. July 23, 1918: Hemothorax with increased pleuritic exudate, right side. Dyspnea. July 24, 1918: Aspiration unsuccessful. Condition poor. Hospital moved forward. Patient left in poor condition August 2, 1918. Died. No further notes.

Notwithstanding severe injuries affecting both pleural cavities and anterior mediastinum, this man had the power to recover had proper primary drainage been employed.

2. A. R. July 20, 1918: Shell fragment, penetrating wound, sucking, right chest. Entrance over scapula. Large hemothorax. Foreign body present. Duration (unknown). Condition (?). Operation: Lacerated tissue excised; fractured scapula and rib resected. Muscles closed over sucking wound in pleura. Foreign body not removed. Severed suprascapular nerve sutured. July 24, 1918: Uncomfortable convalescence. Pleuritic exudate disappearing. Evacuated in good condition. 1921. Records available. Disability below 10 per cent.

This man's recovery was due to good luck rather than to good management. Hole in lung should have been repaired; chest aspirated, possibly drained if the wound was of long duration because of the sucking type.

3. A. F. G. July 21, 1918: Bullet, through-and-through, sucking wound, left chest. Entrance over sixth rib, anterior axillary line; exit, paraspinal line, level of twelfth rib. Hemopneumothorax moderate. Duration (unknown). Condition (?). Operation: Excision of wounds of entrance and exit. Resection of fractured ninth, tenth, and eleventh ribs. No lung injury recognized at operation. Closure of parietal defect. July 24, 1918: Rapid convalescence. Still some hemopneumothorax though disappearing. Evacuated in excellent condition. No further records. Disability (?).

Immediate aspiration was probably employed but not recorded. Subsequent aspiration was indicated, possibly primary drainage if the sucking wound was of more than a few hours' duration.

4. C. J. D. July 22, 1918: Shell fragments, multiple wounds, right jaw, neck, shoulder, and right chest, sucking, perforating. Wound of entrance in second interspace anteriorly. Moderate hemopneumothorax. Heart displaced to left. Duration (unknown). Condition good. Operation: Extrathoracic wounds excised and packed. Wound of entrance excised. Foreign body, thought to be in lung, not sought. Hemothorax aspirated. Parietal wound closed. July 24, 1918: Condition good although pleuritic exudate is not receding. Evacuated in good condition. August —, 1918: Phlebitis right leg. August 30, 1918: Returned to United States. February 6, 1919: Discharged from service. August 5, 1921: Disability attributable to leg alone. Vital capacity 87 per cent. Slight pleural thickening at right base. Heart competent. Foreign body in posterior chest wall.

Another recovery attributable to good fortune. An undrained sucking wound causing no pyothorax. Quite probably this man's condition after excision of multiple wounds prohibited more radical intervention.

5. W. D. S. July 22, 1918: Bullet, perforating wound, left chest. Entrance fifth interspace, midclavicular line; lodgment in ninth interspace, close to vertebra. Moderate hemopneumothorax. Duration (unknown). Condition (?). Operation: Excision of wound of entrance. No rib injury. Opening into pleura closed. Incision over foreign body posteriorly. Foreign body removed. No rib injury. Hemothorax aspirated through defect in parietal pleura which was then closed. July 24, 1918: Easy convalescence. Evacuated in good condition. November 20, 1918: Returned to organization (Infantry). December 20, 1918: Readmitted to hospital because of trouble in knee, supposed to be synovitis. May 10, 1919: Discharged from service. Given a disability of but 10 per cent because of chronic synovitis; none because of chest injury. August 5, 1921: Synovitis proved to be due to sclerosis of pyramidal tract due to injury to spine. Heart and lungs quite normal. Vital capacity, 98 per cent.

Without knowledge of man's condition at time of operation, or duration of wound, it is unwise to say that more radical treatment would have assured better repair. It could have secured none as a zero disability attests.

6. J. H. T. July 23, 1918: Shell fragment, penetrating, sucking wound, right chest. Entrance over scapula; compound fracture of scapula and three subjacent ribs. Small hemothorax. Duration (unknown). Condition fair. Operation: Excision of entrance wound; resection major portion of fractured scapula and ribs. Very large foreign body removed from pleural cavity. Hemothorax aspirated. No lung injury required repair. Closure of pleural defect with muscle flaps and subcutaneous fat. July 24, 1918: Superficial healing good. Some pneumothorax persists. Uncomfortable but otherwise in excellent condition. Evacuated later much improved. 1921: Official record show disability less than 10 per cent.

This recovery is another to be attributed to good fortune as the pleural cavity was much soiled because of a large sucking wound. Suitable drainage would have hastened recovery and made it the more certain.

7. M. D. July 27, 1918: Shell fragments; wounds of left neck and arm with penetrating wound of left chest. Entrance over eighth rib near angle of scapula. Moderate-sized hemothorax. Duration (unknown). Condition (?). Operation: Excision of entrance wound. Fractured eighth rib resected. Inner table of rib found extending into pleural cavity. Hemothorax evacuated. No note on foreign body. Lung distended normally. Muscle closure of pleural defect. Layer closure of superficial structure; drained with gutta-percha. July 31, 1918: Excellent recovery. Pleuritic exudate slight and diminishing. Hemothorax here due to bleeding from rib. Left chest slightly hazy. Foreign body 0.5 by 0.5 cm. in lung. Diaphragm motion present; restricted on left. Evacuated in good condition. Later returned to duty and then lost. Disability (estimated) 10 per cent.

Removal of so small a foreign body from the lung is contraindicated. The case illustrated the wisdom of exploring all chest wounds. The rib injury would otherwise have escaped attention until late complications arose. This man would have benefited by a day or two of primary drainage or one postoperative aspiration.

8. L. E. July 28, 1918: Bullet, through-and-through, sucking wound, right chest. Entrance over right third rib, parasternal line. Exit over ninth rib below angle of scapula. Small hemothorax. Condition poor. Duration (unknown). Operation: Excision of entrance and exit wounds. Fractures of fourth, fifth, sixth, seventh, eighth, and ninth ribs resected. Hemothorax evacuated. Splenized lung not resected because of patient's poor condition. Pleural defect closed with muscle. Death within 12 hours. No notes on necropsy.

This man was lethally injured by the time he came to operation. Nevertheless the splenized lung should have been resected, as allowing it to remain could at the best only postpone death. Earlier operation and multiple transfusions could have been effective.

9. M. S. September 26, 1918: Shell fragment, perforating right chest. Entrance right upper chest, anterior. Exit right lower chest, at level of tenth rib, posterior. Foreign body under skin near vertebra. Right hemothorax, moderate. Abdomen rigid, indicating possible injury to diaphragm. Duration 9½ hours. Condition good. Operation: Eight and a half hours later. Wound of entrance excised. No rib injury. Pleural defect closed by stitching inflated lung to margins and by muscle flaps superimposed externally. Incision over foreign body which was removed and dark blood evacuated. Again no rib injury. Hemothorax aspirated through pleural defect. No lung injury found. Pleura closed with muscle. September 30, 1918: Condition good. Little pleuritic fluid evacuated. January 15, 1919: Returned to duty. Disability (estimated) 10 per cent.

Growing experience led to more effective operations and attempts were made to expose lung injuries. Same fault of not using primary drainage is noteworthy.

10. S. F. S. September 26, 1918: Shell fragment, through-and-through, sucking wound; right chest. Entrance at eighth rib, posterior axillary line. Exit at third rib above scapula. Small hemothorax. Duration 14½ hours. Condition poor. Operation: Begun after six hours' treatment for shock. Entrance wound excised. No rib injury. Hemothorax aspirated. Pleural opening closed. Exit wound excised. Fractured rib resected. Chronic adhesive pleuritis prevented any exploration. Large intrapleural cavity drained. Incomplete layer closure. October 4, 1918: Has done fairly well except for persistent effusion in lower chest from which 1,300 c. c. of blood-stained fluid was aspirated. Culture

negative. Hereafter improvement was more rapid. Evacuated in good condition. Returned to duty in six months. Disability (estimated) 10 per cent.

Recovery would have been hastened by earlier aspiration of pleuritic effusion, though primary drainage would have been still better.

11. M. S. September 26, 1918: Bullet, through-and-through wound, right chest. Entrance wound, anterior, at margin of rectus muscle; exit wound posteriorly over seventh rib. Small hemothorax. Splenization in right lower lobe suspected. Duration 10 hours. Condition fair. Operation: After six and a half hours' preparation. Entrance wound excised. No rib injury. Pleural opening and superficial wound closed. Exit wound excised. Fractured seventh rib resected. Hemothorax aspirated through this pleural opening. Lung injury not repaired. No splenization noted. Parietal pleura defect plugged with muscle. Wound closed in layers. No drainage. October 5, 1918: Wound healing good. Pneumothorax absorbed. Pleuritic effusion persists, but not aspirated. Pneumonia left upper lobe. October 6, 1918: 500 c. c. bloody fluid aspirated from right chest. October 7, 1918: Partial pneumothorax evacuated; condition fair. August 4, 1921: No treatment subsequent to evacuation. Suffers from dyspnea and cyanosis on exertion. Chronic bronchitis, peribronchitis, fibrous pleuritis; dome of diaphragm adherent to ninth rib; myocardial deficiency. Vital capacity, 57 per cent. Disability allowance of 10 per cent much too low; should be 40 per cent.

This man's treatment was improper partly because of battle pressure. A more finished operation with suture of lung wounds should have been performed and with drainage and postoperative care would have hastened recovery and reduced disability, notably in preventing recurrence of pneumothorax. An excellent example of the wisdom of exploring all through-and-through wounds to exclude or to remedy rib injuries. The occurrence of a contralateral pneumonia is noteworthy because so infrequent with positive pressure gas analgesia.

12. J. G. September 27, 1918: Bullet, through-and-through, sucking wound, left chest. Entrance at second rib, parasternal line; exit below and posterior to angle of scapula. Fluoroscopic diagnosis: Moderate hemothorax. Both lobes perforated; splenization of lower part of upper lobe; heart displaced to right; no rib injuries recognized. Duration 12 hours. Condition poor. Operation: Nine hours later during which he was treated for shock. Wound of entrance excised. No rib damage. Closed without drainage. Exit wound excised; revealed sucking wound, fractures of sixth and seventh ribs, which were resected. Fragments of sixth rib had penetrated visceral pleura and were removed; 200 c. c. of fluid blood aspirated. Clots not removed and lung not repaired because of weak condition of patient. October 5, 1918: Stormy convalescence. Considerable effusion with pneumothorax. Evacuated in fair condition. No subsequent treatment. October ?, 1918: Returned to United States. January 23, 1919: Discharged from service. July 29, 1921: Underweight. Dyspnea on extra exertion. Pleuritic thickening base of left lung. Dome of left diaphragm adherent to sixth rib. Shallow pneumothorax cavity beneath seventh, eighth, and ninth ribs covered by thick scar. Lung parenchyma corresponding to injury and to pneumothorax cavity does not function. Myocardium fair. Vital capacity 90 per cent effected by compensatory emphysema. Disability allowance of 18 per cent is low because heart muscle is only competent at rest and has narrowed reserve power.

This man's experience emphasizes important points. The folly of conservatism in treating through-and-through wounds. These rib fractures untreated would have led to persistent pneumothorax. Under favorable circumstances open thoracotomy and radical treatment of lung defects would have been indicated. Splenization may not always cause death but by the resultant scar restricts pulmonary elasticity and causes disability. The

persistent partial pneumothorax is an example of the permanent total pneumothorax that occurs when differential pressures are not employed. Suitable drainage would have corrected this fault. Neglect of breathing exercises through absence of all continued treatment increased the total disability materially and perhaps prevented this man from returning to his pre-war occupation.

13. H. B. September 27, 1918: Shell fragment, penetrating left chest. Entrance wound second left interspace, parasternal line; small foreign body moves with respiration. Hemoptysis marked; hemothorax large; considerable pneumothorax. Duration 24 hours. Condition good. Operation: Two hours later. Wound of entrance excised. Fractured fourth rib at costochondral junction resected. 1,000 c. c. of blood and some clots removed. Wound of entrance into lung not found. Foreign body not sought. Closure without drainage. October 2, 1918: Rapid recovery. Pleuritic exudate slight. No pneumothorax. Evacuated. November 5, 1918: Returned to duty 39 days after injury. April 21, 1919: Discharged from service. No further treatment. August 20, 1921: Complains of pain in left chest and dyspnea with slight exertion. Chronic pneumonia left upper lobe. Chronic pleuritis left base. Adhesions between diaphragm and ninth rib restricts its motion Myocardium, subcompetent. Vital capacity 112 per cent, due to contralateral emphysema Foreign body present near base of lung. Disability 25 per cent, due to heart.

This man's disability is due to scar tissue inside the lung and out. His prompt recovery indicates that the immediate treatment was adequate. The ultimate results show that proper postoperative care, including well systematized exercises, would have brought such a recovery as would have permitted him to return to his original occupation of farming. Again and again the heavy toll placed upon the wounded through failure to provide suitable after-care is exemplified.

14. E. McF. September 27, 1918: Bullet, through-and-through, sucking wound, right chest. Entrance, third rib anteriorly; exit, ninth rib posteriorly. Small hemothorax; large pneumothorax. Duration nine and a half hours. Condition grave. Resuscitation for 25 hours. Operation: Thirty-six hours after injury. Excision of wound of entrance and of exit in posterior axillary line. Compound comminuted fractures of fourth, fifth, sixth, seventh, eighth, and ninth ribs exposed and resected. Lung badly lacerated and splenized. Lacerations trimmed and sutured. Patient's condition was thought to contraindicate resection of splenized lung. Hemothorax removed. Pleural defect closed with muscle flaps over incompletely expanded lung. September 29, 1918: Transfusion 400 c. c. citrated blood. October 5, 1918: Partial pneumothorax above pleuritic exudate. Four hundred c. c. serosanguinous fluid exudate aspirated. Cocci in clumps. October 8, 1918: Somewhat improved. October 21, 1918: Died. Double empyema and peritonitis.

Shock prevented earlier operation and was thought to contraindicate resection of splenized lung. Obviously, resection should have been performed and with suitable drainage demanded by a sucking wound of this duration (36 hours) would have saved this life.

15. I. D. September 28, 1918: Shell fragment, 0.5 by 0.3 cm., penetrating, sucking wound, right chest. Entrance over spine of right scapula, thence through lung, diaphragm and liver to lodge in upper pole of right kidney. Large hemothorax. Duration eight hours. Condition poor. Resuscitation for seven hours. Operation: Fifteen hours after injury. Entrance wound excised. Comminuted fracture of tenth rib resected. Wound in lung insignificant and not repaired. Hemothorax aspirated and clots removed. Parietal defects closed with muscle flaps. No drainage. October 3, 1918: Had done well for a few days. Signs of bronchopneumonia developed yesterday in left lung and fluid in right chest increased. Foul-smelling fluid containing many bacteria aspirated from pocket near angle of right

scapula. Open drainage. October 4, 1918: Died (sixth day after operation). Necropsy: Open drainage had caused some collapse. A second encapsulated empyema had not been reached. Left lower lobe and lower part of left upper lobe almost solid with confluent patches of bronchopneumonia. Abdomen contained small amount of blood. No peritonitis.

Another of the exceptional instances of bronchopneumonia after positive pressure analgesia. Otherwise this man might not have succumbed notwithstanding his poor condition. Should have been drained.

16. O. O. M. September 28, 1918: Shell fragments. Wounds of legs and head, and penetrating, sucking wound, left chest. Entrance over ninth rib below angle of scapula. Moderate hemothorax. Heart displaced to right. Foreign body in left lung. Duration 39 hours. Condition poor. Long journey, exposure and anemia. Resuscitation five hours. Operation: Forty-four hours after injury. Wounds in scalp and thigh excised Wound of entrance to chest excised. Fractured ninth rib resected. Hemothorax aspirated through defect in parietal pleura. Inflation of lung brought lacerations in left upper lobe into view which were bleeding profusely and so were sutured. Foreign body could be felt in lung but removal was not attempted as patient's condition was critical. October 18, 1918: Uneventful recovery. Diffuse pleuritis, left lung. No consolidation. Foreign body, 1.1 by 0.8 cm., present near hilum. Evacuated in good condition. December 28, 1918: Returned to duty (three months). No subsequent record. Disability (estimated) 10 per cent.

This recovery when operation on a sucking wound had been delayed 44 hours illustrates the wisdom of denying none of the wounded the chance to live no matter what the operative mortality rate might be. It would have been wiser under the conditions to have employed primary drainage as the recovery without empyema was most fortunate under the conditions.

17. S. G. October 12, 1918: Bullet, through-and-through wound, left chest. Entrance at tip of left clavicle; exit at vertebral border of left scapula at level of its spine. Small hemothorax. Hemoptysis. Mustard gas burns, right side of face. Duration seven and a half hours. Condition good. Operation: Six hours later. Wounds of entrance and exit excised. Fracture of (?) rib resected. Muscle closed into pleural defect to protect exposed lacerated but adherent lung. Gutta-percha drain. October 14, 1918: Mustard gas burns on face much worse. Few râles noted in right chest. Slight left pleuritic effusion. Evacuated in good condition.

Official records show death from bronchopneumonia (mustard gas) 25 days later. Chest disability would have been less than 10 per cent.

18. H. B. October 15, 1918: Bullet, through-and-through wound, left chest. Entrance over second rib anteriorly; exit over fourth rib posteriorly. Moderate hemothorax. Duration 16 hours. Condition poor. Operation: Entrance and exit wounds excised. Fractured second rib anteriorly and third and fourth ribs posteriorly resected. Hemothorax aspirated. No lung repair. Pleura closed with muscle flaps.

October 16, 1918: Patient continues cyanotic. Tachycardia. No increase in pleural effusion. Died at noon. No necropsy. Death attributed to myocardial fatigue.

Less extensive operation incompatible with recovery; more extensive not indicated. Digitalis before and after operation with hypertonic glucose intravenously might have been effective. May be called a lethal injury.

19. J. C. October 15, 1918: Bullet, through-and-through wound, right chest. Entrance at inner end of clavicle; exit beneath spine of right scapula. Small hemothorax. Much bone damage. Condition grave. Duration 29 hours. Resuscitation 10 hours. Operation: Thirty-nine hours after injury. Entrance wound ignored. Exit wound excised. Scapula turned forward. Comminuted fracture of scapula and one rib resected. Hemo-

thorax aspirated. No lung injury repaired. Closure with superficial drainage. Stations changed. Learned of death but not its cause. No necropsy. Death attributed to shock.

Another example of a simple injury made lethal by delay and exposure.

20. L. L. October 19, 1918: Shell fragments, multiple wounds; compound fracture right femur; penetrating right chest. Entrance eighth interspace posterior axillary line. Foreign body, 2 cm. by 2 cm., immobile in right upper chest. Small hemopneumothorax; heart displaced to left; middle and upper lobes involved. No hemoptysis. Duration 20 hours. Condition serious. Operation: Entrance wound excised. Fractured ninth and tenth ribs resected. Small hemothorax. Clots and fibrin removed. Hole in lung sutured. Foreign body not removed. Area of splenization not resected because of lack of space. Closure with superficial drain. Wound of thigh excised. Compound fracture of femur splinted. October 22, 1918: Pleuritic effusion increased and was aspirated. Bronchopneumonia and pleurisy, both lobes of left lung. Death. Necropsy: Bronchopneumonia left upper and lower with fibrinous pleurisy. Right lower lobe contained a tunnel wound in which were bone fragments; widely splenized. Fibrinous pleurisy. Upper and middle lobes normal.

This man's chance for recovery depended upon his chest repair. It would have been wiser here to have opened the chest widely, excised the lower lobe and neglected the thigh wound even if this meant ultimate sacrifice of leg. Another example of the serious import of splenization and of contralateral bronchopneumonia.

21. R. H. November 2, 1918: Shell fragments, left wrist; through-and-through wound, right chest. Entrance wound upper anterior chest; exit, posterior. Small hemothorax. Superficial wound left wrist. Condition good. Duration 24 hours. Operation: Entrance wound excised. Lung adherent. Closure with muscle flap. Exit wound excised. Slight rib injury resected. Hemothorax aspirated. Closed without drainage. Wrist wound dressed. November 11, 1918. Easy convalescence in spite of right-sided pleurisy and return of partial pneumothorax. Evacuated. Could not be traced.

A more radical operation at exit would have repaired lung injury, prevented recurrence of pneumothorax, and reduced the pleuritic effusion which should have been aspirated. Drainage would have been better.

SUMMARY OF GROUP II

The number treated by limited thoracotomy (21) was about 20 per cent of the series. The number would have been larger had the unit had more of the less severely injured to treat and had the possibilities of such operations been appreciated.

Fatalities.—There were eight deaths (40 per cent). One (17), slightly wounded, died on the 25th day from bronchopneumonia due to mustard gas. His chest disability would have been less than 10 per cent. Three (8, 18, 19) were lethally affected at time of operation because of delay and exposure. One (18) died from myocardial exhaustion which had been incurred before injury. Three developed pyothorax (1, 14, 15). Two (1, 14) might well have recovered had more radical surgical treatment and primary drainage been employed. The third (15) had advanced contralateral pneumonia which possibly was traceable to failure to drain. One (20) suffered from other injuries, including a compound fracture of a thigh. Had the thigh wound been given less attention and the splenized portion of a lung resected, a recovery, perhaps with amputation, was conceivable. Duration from injury to operation was

from 9 to 39 hours, average 23 hours. Mortality chargeable to surgical errors, too conservative treatment of injured lung, and failure to drain is 15 per cent.

Disabilities.—Late disability ratings are dependably established for 11 of the 13 who recovered. Two (4, 5) made complete recoveries. Two (2, 6) are rated at less than 10 per cent; five (7, 9, 10, 11, 16) at 10 per cent; one (2) at 18 per cent, and one (13) at 25 per cent. Two (11, 12) have unjustly low ratings. The disability of one (13) is due to cardiac incompetence. Two (3, 21) were not estimated. The average disability is probably not far from 10 per cent, but is set at 13 per cent to err on the safer side. The few notes available showed from 39 to 180 days interval before return to duty, average about 100 days.

Pleuritis is the cause of disability in all but the one (13) due to myocardial deficiency. An average disability of even 13 per cent is gratifying when it be considered that some of these wounds were "suckers" and their duration about 24 hours, and also that none received proper postoperative care. The two who received unfairly low ratings had complications, one (11) had pneumonia and the other (12) a persistent pneumothorax and a lung scar resulting from splenization.

It is again evident that a reduction of the interval between injury and operation would have reduced mortality and disability rates; the latter (13 per cent) would also have been favorably influenced by less conservatism in operating, a more general use of primary drainage and constant after-care. The duration of disabilities estimated at one hundred days upon the few notes at hand is higher than the truth and avoidably high.

DEDUCTIONS

Operations that can be classed as limited thoracotomies are applicable to those wounds that can not be safely treated by parietal excisions and to those severely wounded who can tolerate but little more than parietal excisions. The same methods, especially positive pressure gas analgesia, are indicated. Limited thoracotomy gives opportunity to repair less significant lung injuries, to aspirate pneumothorax with a cannula instead of a needle and at times to remove clots. Its disadvantages are incomplete exposures and the consequently great dangers of overlooking lesions that should be repaired. Its advantages are shorter and less trying operations and less interference with parietal integrity.

CONCLUSIONS

The more severe the injury, the greater the necessity for prompt intervention. Operations of the limited thoracotomy type were employed too infrequently and possibly can be used more generally and more effectively hereafter if the routine after care is improved so that postoperative complications would receive prompt recognition and correction.

During periods of active fighting many of the wounded who might be well served by limited thoracotomy could be transported to evacuation hospitals for first treatment. A great danger lies in too conservative operating upon lung wounds. The objection to limited thoracotomy is its ease and rapidity of per-

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formance and apparent safety when real conservatism would be a more radical operation.

The need for preoperative resuscitation of those in shock and the prevention of postoperative shock becomes more and more evident. Gum acacia proved of value when properly used and was a source of danger when improperly used, which was the rule. Hypertonic glucose and other solutions may be of more benefit than gum and should be provided. The most help comes from blood transfusions. Larger amounts of blood should be made available.

GROUP III. THORACOTOMY OF NECESSITY

1. A. B. July 21, 1918. Shell fragment, large, freely bleeding, sucking, tangential wound, left chest. Entrance at fifth interspace, midclavicular line. Tissue emphysema. Large pneumothorax. Small hemothorax. Condition poor. Duration unknown. Operation: Lacerated soft parts excised; broken ribs resected. Lung wounds repaired. Flap closure. Death in 12 hours. Necropsy: Slight hemothorax. Lung repair and parietal closures adequate and apparently secure.

Multiple transfusions might have prevented this death.

2. H. K. July 27, 1918: Shell fragments; penetrating and through-and-through sucking wounds both chests. Main wound entrance seventh rib, right scapular line; exit seventh rib, left scapular line. Bilateral hemopneumothorax, right larger. Condition (?). Duration unknown. Operation: Entrance wound excised, exposing sucking wound. Fractured seventh rib resected. Crater defect in lung contained bone fragments. Fragments removed, bleeding controlled, lung approximated over defect but incompletely as man's condition contraindicated wider exposure. Pleural defect closed with aid of wire rib stay. Superficial wound drained. Wound of exit excised. No rib damage. July 31, 1918: Good recovery. Postoperative tissue emphysema showed that repair of lung wound had not been airtight. Left side, effusion absorbed. Right side, effusion is increasing. August 1, 1918: Spontaneous discharge of serum from right side. Partial pneumothorax. Evacuated in good condition. February 1, 1919: Returned to duty in 180 days. Disability 10 per cent.

Slightly wider exposure, more accurate closure of lung wound, right-sided drainage and aspiration of left chest would have been wiser.

3. V. I. P. July 27, 1918: Shell fragment, through-and-through, sucking wound, left chest. Entrance over 6th rib lateral to midclavicular line; exit ninth rib, posterior axillary line. Moderate hemothorax; heart displaced to right. Splenized lung seen fluoroscopically. Condition (?). Duration 30 hours. Operation: Entrance and exit wounds excised; fractured eighth and ninth ribs resected. Splenized lung excised. Pleural closure effected with wire rib stay. Layer closure. Superficial drain. July 31, 1918: Fluid in left chest receding. Patient sitting upright. Evacuated. Condition good. August 15, 1918: Pneumonia, left side, followed by empyema and treated with rib resection. Drainage tract closed spontaneously. February 8, 1919: Discharged from Army. July 21, 1921: Underweight, languid, dyspneic. Scoliosis, reduced expansion, left chest; chronic pleuritis, limited motion and adhesions of diaphragm. Vital capacity 78 per cent. Disability 40 per cent (estimated).

Pneumonia caused by compressed lung because of effusion. Drainage would have lessened, had it not prevented this complication.

4. T. B. B. July 28, 1918: Shell fragment, through-and-through wound, left chest. Entrance seventh interspace anterior axillary line; exit tenth rib posterior axillary line. Condition (?). Duration unknown. Operation: Wounds excised; fractured ninth and tenth ribs resected; lacerated and splenized portions of lower lobe resected. Two tears in diaphragm sutured. Wound in liver not treated. Pleural closure incomplete even with

rib stay so reenforced with muscle. July 31, 1918: Slight effusion; no pneumothorax. Motion of diaphragm reduced. Evacuated. July 30, 1921: Pain and dyspnea on extra exertion. Chronic pleuritis at left base with adhesions between dome of diaphragm and eighth rib. Excursions of diaphragm restricted. Wire rib stay has parted. Vital capacity 90 per cent. Heart competence slightly reduced. Disability rating of 35 per cent is too high.

Wire stay should have been removed. Primary drainage and postoperative exercises would have reduced disability.

5. M. D. August 1, 1918: Shell fragment, penetrating right chest. Entrance wound ninth rib, paravertebral line. Foreign body, two cm. by three cm., in lung, which is cloudy. Moderate hemothorax; heart slightly displaced; diaphragm immobile. Condition good. Duration (?). Operation: Entrance wound excised; ninth rib, fractured just anterior to its angle, resected; hemothorax evacuated; foreign body removed from posterior aspect lower lobe. Lung wounds sutured. Pleura closed after ribs were approximated with wire stay. Layer closure of soft parts. No drain. July 21, 1918: Effusion to level of angle of scapula. Good condition. Healing satisfactorily. Subsequently evacuated in good condition. No further treatment. January 31, 1921: Discharged from service. August 19, 1921: Slight pain and dyspnea on exertion. Fibrous pleuritis at right base. Diaphragm adherent to eighth rib and excursions reduced. Heart competent. Wire rib stay broken. Vital capacity 81 per cent. Disability of zero is too low.

Wire rib stay should have been removed. Aspiration, or better still drainage, would have reduced pleuritis. Lack of proper exercises prevented a perfect recovery.

6. M. P. August 1, 1918: Shell fragments, multiple, penetrating, sucking wounds, right chest, liver and colon. Entrance chest, ninth rib, anterior. Condition poor. Duration 10 hours. Operation: Resection compound fracture ninth rib. Multiple lung wounds, liver and colon. Wounds sutured as rapidly as possible because of man's condition. August 2, 1918: Died. Necropsy: Hemothorax right, splenization of middle lobe, collapse of lower lobe. Wound repair adequate.

Lethal injury at time of operation.

7. A. H. B. August 1, 1918: Shell fragment, left scapula, sucking, penetrating wound, chest. Bullet wound, right shoulder, penetrating. Foreign body, 1.5 cm. by 3 cm. in left upper thorax. Chest hazy; diaphragm fixed. Condition desperate. Duration 12 hours. Operation: Excision entrance wound; resection left scapula and fractured fourth rib. Excision and suture of bleeding wound in upper lobe. Foreign body removed. Rib stay and muscle flap closure. Bullet wound ignored as patient had been carried this far with two gum-salt infusions. August 2, 1918: Slightly better. Blood transfusion. Fluid up to angle of scapula. Slight pneumothorax. August 3, 1918: Condition about the same. Unit moved to another station. August 5, 1918: Died. No notes. No necropsy.

Severely wounded man in shock. Death probably due to pyothorax. Should have had primary drainage and blood transfusions before operation.

8. E. K. August 8, 1918: Shell fragments, right wrist, superficial, and through-and-through, sucking wound, right chest. Entrance just to right of spine above angle of scapula. Tissue emphysema here. Exit at second rib midclavicular line. Right chest hazy. Condition poor. Weather hot, water scarce, troops fatigued. Duration 12 hours. Operation: Entrance wound excised. Compound fracture eighth rib resected. Lung adherent, lacerated and contains many bone fragments, resected and repaired as well as exposure and adhesions permitted. This area was drained as there was no connection with pleural cavity. Exit wound excised; fractured second rib resected. This tract also drained for same reason. August 15, 1918: Pyothorax and septicemia caused death. Aspirations, open drainage, and transfusions were futile. No necropsy.

This man was operated upon during a pestilence of flies that could not be kept off dressings or out of wounds; doubtful if it would have been possible to avoid this death.

9. J. F. C. August 8, 1918: Shell fragments, through-and-through wound, right arm and right chest. Notes few and vague. Entrance at angle of tenth rib; exit, anterior aspect of chest. Condition (?). Duration 55 hours. Operation: Entrance wound excised; fractured tenth rib resected. Large hemothorax and many clots removed. Lung sutured. Pleural defect repaired by stitching diaphragm to margins. Anterior entrance wound excised; rib not injured. Tear in lung not found. Wire rib stay used to obtain closure of pleural defect. Wound in arm excised and packed with gauze. August 17, 1918: Slight effusion persists. Evacuated in good condition. August 17, 1921: Notes by Doctor Byrne. "No parenchymatous lesions; dome of diaphragm adherent to seventh rib is flattened." Disability, vital capacity and myocardial competence unknown. Disability (?).

This patient illustrated the need of breathing exercises to reactivate a diaphragm, particularly after it has been sutured to the parietes. An excellent example of the wisdom, accepting all risks with faintest chance for recovery. Without operation this man's life expectancy would have been zero.

10. W. B. August 8, 1918: Shell fragment, large, penetrating, sucking wound, left chest. Entrance ninth rib, costochondral juncture. Condition good. Duration unknown. Operation: Wound excised; fractured ninth rib resected. Foreign body, found on diaphragm which was lacerated, was removed. Diaphragm sutured. Hemothorax and clots removed. Lung and diaphragm sutured. Closure with wire rib stay. August 17, 1918: Uncomfortable convalescence. Slight pneumothorax. Pleuritic effusion moderate and not aspirated. Suppuration occurred but did not cause pyothorax because the repair of parietal pleura had been adequate. Evacuated in good condition. February 13, 1919: Discharged from service having had otitis media which caused deafness. August (?), 1920: Wire rib stay removed. August 31, 1921: Some pain. No dyspnea. Underweight. Chronic pleuritis left base; diaphragm adherent to parietes. Reduced myocardial reserve power. Disability, 38 per cent, not all due to chest. Vital capacity, 78 per cent. Disability, 15 per cent, due to chest, is liberal.

Wire rib stay should have been removed earlier. Excellent example of obtaining firm parietal pleural healing to prevent pyothorax. Aspiration and breathing exercises would have limited disability.

11. G. F. August 8, 1918: Shell fragment, perforating left chest. Entrance below middle of left clavicle; exit into soft parts beneath scapula. Condition poor. Duration six hours. Operation: Wounds excised; fractured ribs (second, third, and fourth) resected. Laceration and splenization left upper lobe. Laceration repaired; splenized lung not resected. Hemothorax aspirated. Pleural defect closed with muscle flaps. Posterior wound drained after removal of foreign body. Returned to shock ward with pulmonary edema. No response to treatment. Death in 16 hours. Necropsy: Pulmonary edema, hypostatic congestion both lungs. Dilatation, right heart. Splenization left upper lobe. Suture line intact.

This patient might have been saved, probably would, had he been wounded later when experience was larger. He would have been better prepared for operation. Splenized lung should have been resected. Too high positive pressures were used in a futile attempt to re-inflate lung. Abruptly increased peripheral resistance added to that already present sufficed to cause dilatation of right heart and thus to provoke pulmonary edema.

12. German soldier. August 8, 1918: Shell fragment, seton wound over anterolateral aspect sixth rib, left. Condition poor. Duration 56 hours. Operation: Wound excised.

Fractured sixth rib resected. Lower one-half of upper lobe and most of lower lobe splenized. Fibrinous exudate on visceral pleura. Pleural cavity contained thin, red fluid (streptococcus?). Pericardium used to assist closure of pleural defect. Death soon after operation. No necropsy.

Illustrates severe types of splenization caused by tangential injury without laceration of lung. Also shows the greater reactability of visceral pleura upon which the fibrinous exudate had been formed. It is doubtful if prompt operation could have prevented a fatal issue because removal of almost all of the left lung would have been necessary.

13. M. S. August 9, 1918: Shell fragment, penetrating wound, left chest. Wound of entrance over sixth costal cartilage at sternal articulation. Moderate hemopneumothorax. Condition (?). Duration four hours. Operation: Wound of entrance excised. Margin of sternum and sixth costal cartilage resected. Hemothorax evacuated. Foreign body removed. No notes on lung injury and repair. Lung completely inflated. Closure difficult because of a defect close to sternum. August 16, 1918: Interstitial emphysema about wound and reappearance of pneumothorax showed that pleural closure had been inadequate. Moderate pleuritic exudate. By this time, emphysema, pneumothorax and effusion all were less. Excellent general condition. January 4, 1919: No further operative treatment; indeed, none of any kind. Discharged from service. Disability 80 per cent. August 17, 1921: Tachycardia and dyspnea follow slight exertion. Frequent pain referred to lower left chest. Dome of left diaphragm adherent to parietes. Chronic pleuritis left base. Cardiac response to exercise poor. Left heart enlarged. Vital capacity, 55 per cent.

Disability due in part to myocardial incompetence which in part is attributable to intrathoracic lesions. Rating of 80 per cent is too high. Aspiration after operation and suitable care would have hastened convalescence and reduced disability.

14. E. K. K. August 11, 1918: Shell fragment, perforating wound, left chest. Entrance second interspace just lateral to sternum. Exit through scapula to lodge in infraspinatus muscle. Condition poor. Duration five hours. Operation: Excision entrance wound; resection second costal cartilage and part of second rib. Hemothorax aspirated; clots removed. Lung drawn out and perforation sutured. Lung sutured to close defect in parietal pleura which could not be approximated even with two wire rib stays. Foreign body removed from infraspinatus muscle. No attempt made to open chest posteriorly, as no rib injury was present and patient's condition was poor. Despite blood transfusions and infusions, patient died within 12 hours. Necropsy: Moderate splenization left upper lobe. Posterior perforation not closed. Hypostatic congestion right lung.

Extent and duration of anatomic injuries and severity of operation do not explain death, which must be attributed to general and myocardial exhaustion previous to injury. Splenization should have been noted at operation.

15. W. S. August 12, 1918: Shell fragment, penetrating wound, right chest. Entrance sixth interspace anterolateral aspect. Condition good. Duration four hours. Operation: Wound excised; ninth and tenth ribs, fractured in posterior axillary line, resected. Tangential wound of lung. Moderate splenization. Hemothorax evacuated. Resection and suture of lung. Pleural closure obtained with two wire rib stays. Layer closure of soft parts. No drainage. August 17, 1918: Limited pleuritic effusion. Condition excellent. November —, 1918: Returned to duty. Disability less than 10 per cent.

Aspiration should have been performed. Wire rib stays should have been removed. Despite errors and omissions in treatment, the man is reported to have participated in active fighting again.

16. P. F. M. August 17, 1918: Shell fragments (three), penetrating wounds, right chest. No notes on condition or duration. Condition probably unsatisfactory, as was

the rule with the wounded from this division. Moreover, the hospital facilities were wretched. For example, when this man was treated the electrical plant was not working. There was no X ray; no current for headlight. Operation: Wound of entrance over tenth rib in midaxillary line excised; fractured rib resected; pleural cavity opened widely and hemothorax evacuated. Injuries to lung not severe. Two small foreign bodies not removed. One perforating wound of diaphragm and penetrating wound of liver. Exploration failed to locate foreign body. Tract in liver packed with gauze which was brought out through laceration in diaphragm. The diaphragm was then sutured to parietal pleura for partial closure and to protect pleural cavity from bile. Operation unsatisfactory because of no headlight. Balance of closure secured with aid of a wire rib stay. August 20, 1918: Condition excellent. Slight pleuritic exudate. Evacuated shortly. February 28, 1919: Passed through several hospitals in France. No further surgical treatment until to-day when wire rib stay was removed. April 29, 1919: Because of persistent pain two shell fragments were removed from lung. September 18, 1919: Pain still persists. Foreign body removed from liver. August 4, 1921: Pain in lower right chest; dyspnea on exertion; hemoptysis at intervals. Parietes affected by scar and removal of two ribs, one additional rib and part of scar from futile removal of foreign bodies. Restricted expansion of right lower chest; restricted motion of right diaphragm; chronic adhesive pleuritis. Heart competent. Vital capacity, 66 per cent. Disability of 35 per cent is fair.

Foreign bodies might better have been removed at first operation, although they did no harm. Wire rib stay should have been removed in a few weeks. Subsequent care would have reduced disabilities. It is noteworthy that removal of foreign bodies did not relieve pain, introduced hemoptysis, and increased disability.

17. J. T. A. September 12, 1918: Shell fragment, sucking, tangential wound, left chest; entrance fourth interspace, left midaxillary line; exit ninth interspace, midscapular line. Moderate hemopneumothorax; tissue emphysema; heart displaced to right; left diaphragm motionless. Condition poor. Duration five hours. Operation three hours later: Wounds of entrance and exit excised and united. Fractured eighth and ninth ribs resected. Multiple tears in parietal pleura. Wound of entrance in upper lobe not exposed. Wound of exit, lacerated and contained many bone fragments, was resected and repaired. Hemothorax removed. Closure obtained with one wire stay; suturing lung to parietes was unsatisfactory and assured subsequent emphysema. Superficial closure also incomplete. Shock prevented exact methods. September 21, 1918: Recovery in spite of complications. Interstitial emphysema developed, followed, as it commonly is, by suppuration, and finally an open pyothorax. Evacuated in fair condition. February 18, 1919: Suppuration continued. Ribs resected and wire stay removed. July 7, 1920: Hospitalized for three months because of suspected, but not proved, pulmonary tuberculosis. August 11, 1921: Underweight; frail; pain and disability upon exertion. Parietal scars and defects limit expansion of lower left chest. Pericardium adherent to diaphragm and diaphragm to parietes; pleural thickening. Heart competent. Vital capacity, 106 per cent. Disability rating of 75 per cent is higher than findings warrant.

A more finished operation should have been performed to secure better healing. Drainage could have been employed to reduce dangers of pyothorax. This patient illustrates the harm coming from provisional suturing of sucking wounds. His after-care was not satisfactory.

18. F. F. September 12, 1918: Shell fragment, perforating wound, left chest. Entrance posterior axillary fold at level of angle of scapula. Foreign body, .4 cm. by 1 cm., in erector spinæ muscles. Condition (?). Duration six hours. Operation: Entrance wound excised. Fractured ninth rib resected. Hemothorax evacuated. No lung injury seen. Second incision posteriorly over shell fragment failed to discover the foreign body but revealed more serious rib injuries. A third incision made lateral to the second. Rib fractures resected; pleura opened, revealing tangential injury in lung containing bone fragments. Fragments removed; lung resected and sutured; more blood and many large clots

removed. Closure obtained with one rib stay. September 21, 1918: Some pneumothorax persisted. Slight pleuritic effusion absorbed after aspiration of 75 c. c. sterile bloody fluid. Temperature varied from 99° to 102° in spite of smooth healing; 97° on evacuation. 1921: Records show disability less than 10 per cent.

Another illustration of the more serious injury occurring at exit wound and of the wisdom of thorough exploration of all possible parietal injuries. Had the posterior wound been neglected, pyothorax and possibly death would have occurred. The wire rib stay should have been removed.

19. J. R. September 12, 1918: Shell fragment, penetrating wound, left chest; entrance lateral to spine at level of tenth rib. Foreign body in lung (3.5 cm. by 3.5 cm.). Considerable hemothorax. Shock treatment. Duration unknown. Operation: Entrance wound excised. Fractured ribs resected. Entrance wound into lung not found. Foreign body not removed because patient's condition was critical. Large hemothorax evacuated. Closure with wire stay unsatisfactory. Prognosis for healing, poor. Shock treatment. September 21, 1918: Stormy convalescence. Superficial suppuration but no open pyothorax. Pneumothorax with pleuritic effusion; 600 c. c. serosanguinous fluid aspirated and superficial drainage instituted. Convalescent four months. Final records not available. Estimated disability 15 per cent.

Attempt should have been made to repair entrance wound into lung. Primary drainage should have hastened recovery.

20. H. W. September 12, 1918: Shell fragments, multiple wounds, viz, compound fracture upper third, right tibia, foreign bodies in knee, calf and thigh; sucking wound, left chest. Entrance at eighth rib, anterior axillary line; foreign bodies in upper left chest and below dome of diaphragm, thought to be in lung tissue. Hemoptysis and hematemesis. Condition so critical that thorough examination was impossible. Shock treatment for eight hours before operation. Duration (?). Operation: Wounds in extremities excised and foreign bodies removed. Entrance wound into chest excised. Fractured eighth rib resected. Foreign body not found. Search for perforation in diaphragm unsuccessful. Large hemothorax evacuated. Closure with one wire stay. Transfused. September 13, 1918: Condition continued fair until sudden weakening at noon. Transfusions unavailing. Died at 2.30 p. m. Necropsy: Peritonitis, lesser cavity, hemoperitoneum, through and through wounds of spleen and stomach. Chronic nephritis.

This patient's condition was so critical that preoperative examinations were restricted. Intra-abdominal injuries were suspected but a laparotomy was impossible. His one chance was that he could take care of his peritoneal wounds spontaneously. His injuries were lethal when he reached the hospital.

21. H. B. (German soldier). September 13, 1918: Shell fragment, perforating wound, right chest. Entrance, ninth rib posteriorly; foreign body beneath right clavicle. Condition fair. Duration 15½ hours. Operation: Entrance wound excised. Fractured ninth rib resected. Upper lobe adherent, previous pleurisy. Lower lobe, craterlike defect, excised and sutured. Hemothorax evacuated. Wire rib stay. Inflated lung sutured into parietal pleural defect. Foreign body removed from beneath clavicle. No rib injury. Closure without drainage. September 21, 1918: Evacuated; condition excellent. Disability estimated at 10 per cent.

22. M. R. S. September 17, 1918: Bullet, through-and-through wound, right chest. Entrance just below angle of scapula; exit just above nipple, both sucking. Slight hemothorax. Condition good. Duration unknown. Operation: Entrance wound excised. Ninth rib, incompletely fractured, resected. Large laceration, lower lobe, resected and repaired. Hemothorax evacuated. Pleural repair incomplete. Lung sutured into defect. Wound of exit excised. No rib injury. Lung wound closed with purse-string suture and sewed into parietal defect. September 20, 1918: Condition remarkably good. Healing excellent. 1921: Records show disability of less than 10 per cent.

Treatment given to this man was effective except for postoperative exercises. Another example of the value of exploring all through-and-through bullet wounds even though the wounded are in splendid condition.

23. O. B. (German soldier). September 13, 1918: Shell fragment, through-and-through wound, left chest. Entrance below outer third of clavicle; exit below angle of scapula. Condition (?). Duration unknown. Operation: Excision of entrance and exit wounds revealed fractures of second, third, fourth, fifth, sixth, seventh, and eighth ribs in axillary line. Resected ribs exposed deep gutter wound in left upper lobe which was adherent and made lung resection and repair difficult. Large hematoma evacuated from beneath pectoralis major muscle. Plastic closure. September 20, 1918: This man's recovery was remarkable. None others survived such severe multiple rib injuries. Another example of the wisdom of operating despite unfavorable prognosis.

24. H. D. B. September 26, 1918: Shell fragments, through-and-through wound, left thigh, and penetrating wound, right chest. Foreign body, 8 cm. by 10 cm., beneath lower sternum. Entrance posteriorly over twelfth rib. Condition (?). Duration five hours. Operation two hours after admission: Through-and-through wound left thigh excised and drained. Large entrance wound of chest excised. Fractured eleventh and twelfth ribs resected. Foreign body had lacerated diaphragm and liver and lodged in diaphragm beneath sternum. No lung injury. Bile in pleural cavity. Large hemothorax removed, likewise foreign body. Wounds in diaphragm sutured. Drain inserted between liver and diaphragm and diaphragm sutured to parietal pleura to aid in closure and to exclude drain from pleural cavity. October 8, 1918: Satisfactory convalescence. Slight pleuritic effusion. Suppuration in superficial wound but no open pyothorax. Disabled for six months. Ultimate disability less than 10 per cent (estimated).

Delayed recovery due to lack of proper exercise. Primary drainage indicated because of bile in pleural cavity and tendency to cause empyema.

25. C. P. F. September 26, 1918: Shell fragments, through-and-through wounds, left arm near axilla, and left chest. Entrance, seventh interspace, midaxillary line; exit, tenth interspace midscapular line. Paresis of flexors of first finger. Moderate hemopneumothorax. Heart displaced to right. Condition poor. Resuscitation 6½ hours. Duration 11 hours. Operation: Excision wound in upper arm; suture of injured nerve trunk. Wounds of entrance and exit excised and joined. Fractured tenth rib resected. Lacerations in lower lobe and in diaphragm repaired. Parietal closure without drainage. September 29, 1918: Condition and healing satisfactory. July 28, 1921: Duly severe symptoms referable to arm. Slight fibrous pleuritis, left base; diaphragm free. Vital capacity 97 per cent. Disability (chest) zero.

Operation not only protected this man from death, but initiated a perfect recovery. Illustrates advantage of exploring all wounds and giving deep injuries proper treatment. Thoracotomy, even when patients are in poor condition, can be less dangerous than hemothorax.

26. W. S. September 26, 1918: Bullet, penetrating left chest; entrance, third interspace, parasternal line. Bullet beneath sternum moves with respiration, but not with heart beat. No hemoptysis. No hemothorax. Friction rub audible over precordium. Mediastinal emphysema (?); hemopericardium (?); pulse slow but irregular. Condition fair. Duration five hours. Operation six and one half hours later: Entrance wound excised. Bullet found with its nose penetrating the wall of a serous cavity, probably pericardial. Bullet removed and hole closed with suture. Path of bullet extrapleural. Wound closed tight. September 29, 1918: Signs and symptoms cleared since operation. Healing excellent. 1921: Disability less than 10 per cent.

Removal of this foreign body was required. Result shows methods were good.

27. M. J. T. September 29, 1918: Bullet, through-and-through, sucking wound, right chest. Entrance, ninth rib, posterior axillary line; exit, slightly lower in anterior axillary

line. Both plugged with gauze. Hemoptysis. Moderate hemopneumothorax. Resuscitation for four hours. Duration nine hours. Operation: Entrance and exit wounds excised and joined. Portion of ninth rib, found dangling into pleural cavity, removed, and ends of ninth rib resected. Gutter wound in lung excised and sutured. Lung could not be entirely reinflated, so stitched to parietes. Large hemothorax evacuated. Closure unsatisfactory. Patient's condition prevented a finished operation. Given 700 c. c. of gum salt solution on operating table. October 18, 1918: Complicated convalescence ending in open pyothorax. December 1, 1918: Drainage ceased. No further operations. July 29, 1921: Suffers from pain and dyspnea on moderate exertion. Chronic pleuritis. Diaphragm attached high to parietes. Myocardial competence slightly impaired. Vital capacity, 77 per cent. Disability allowance of 20 per cent is low.

Partial inflation of lung at operation indicated need of one-way drainage, as it suggested probable empyema. Even this imperfect operation, made possible by exploration, contributed to recovery as it eliminated bone fragments and osteomyelitis of ribs as a complication of empyema.

28. C. H. September 26, 1918: Bullet, perforating wound, right chest. Entrance close to spine at level of angle of scapula; exit from chest at second rib to lodge beneath the skin. Small hemothorax. Condition poor. Duration 14½ hours. Operation: Sixteen hours later; delay for resuscitation. Wound of entrance excised. Incision made to remove foreign body. Wounds united. Fractured second, third, fourth, fifth, and sixth ribs resected. Parietal pleura lacerated; visceral pleura intact. Hemothorax (1,500 c. c.) removed. Airtight pleural repair. Wound closed without drainage. October 2, 1918: Rapid recovery. Healing smooth. August 19, 1921: No treatment subsequent to operation. Pain with sudden exertion. Overweight. Myocardium competent. Restricted parietal mobility due to malunion of fractured ribs. Vital capacity 87 per cent. Disability of 20 per cent is high.

No better results obtainable without after-care. Removal of rib fragments and immediate reinflation protected this man against empyema and pulmonary compression.

29. T. E. L. September 26, 1918: Bullet, through-and-through wound, right chest. Entrance at level of twelfth rib posteriorly; exit at fifth interspace, anterior axillary line. Moderate hemothorax. Paralysis of right diaphragm. Hematuria. Condition fair. Duration nine hours. Operation four hours later: Entrance wound excised; incision carried along twelfth rib, which was fractured and was resected. Kidney delivered. Subcapsular clots removed and large transverse tear repaired. Laceration in liver drained and in diaphragm sutured. Hemothorax evacuated. Puncture wound of lung not repaired. Parietal pleura closed. Exit wound excised; no rib injury found. Closed tight. October 18, 1918: Good recovery. Slight amount of pleuritic effusion. Free drainage of urine and bile, but temporary. Evacuated in good condition. Later suffered from influenza. July 30, 1921: Complains of pain and weakness in right chest. Some fibrosis of lower lobe of lung. Diaphragm but little affected. Pronounced scoliosis. Vital capacity 92 per cent. Disability rating 100 per cent is ridiculously high. Needs only vocational training to be self-supporting.

Suitable postoperative care would have reduced this man's disability and enabled him to enter a profitable occupation.

30. J. A. September 27, 1918: Bullet, perforating, sucking wound, right chest. Entrance over eleventh rib, midscapular line; exit through diaphragm into liver. Large hemothorax. Condition fair. Duration 14 hours. Operation: Twelve hours later: Entrance wound excised; fractured twelfth rib resected. Perforations in lower lobe, diaphragm and liver repaired. Foreign body not found. Hemothorax, bile-stained, evacuated. Closure unsatisfactory. October 3, 1918: Residual pneumothorax absorbed. Slight pleuritic exudate. Condition good. July 29, 1921: Suffered from influenza before leaving France. Otherwise recovery without complications or after-care. Complains of pain in right chest

and is easily fatigued. Cardiac competence is fair. Fibrous pleuritis at right base. Diaphragmatic excursions limited by adhesions. Disability of 20 per cent is adequate.

Recovery by good fortune. Bile in pleural cavity usually produces an intense reaction and needs primary drainage.

31. C. C. September 26, 1918: Bullet, penetrating, sucking wound, right chest. Entrance, sixth interspace, midaxillary line, lodgment back of heart. Condition wretched. Blood pressure 68/50. Duration 9½ hours. Resuscitation treatment, pressures raised in 3 hours to 90/65. Operation: Eleven hours later: Entrance wound excised; fractured sixth rib resected. Three holes in lung repaired; fourth could not be reached. Bullet removed from behind heart. Difficulty in checking hemorrhage from azygos vein. Large, clotted hemothorax removed. Tight closure obtained. Gum salt given at close of operation. October 10, 1918: Developed contralateral pneumonia after operation. Empyema developed; wound opened revealing a bronchial fistula, the probable cause of empyema and possibly attributable to unclosed perforation. Death fourteenth day. No necropsy.

Man's condition thought to be too precarious to justify opening chest widely enough to repair fourth perforation. This might have saved life. So far as known this is the only bronchial fistula that occurred. This is an excellent example of resuscitation.

32. G. S. (German soldier). September 27, 1918: Shell fragment, sucking, penetrating wound, right chest. Entrance over tenth rib anterior axillary line. Foreign body three cm. by three cm. lodged in liver. Large pneumohemothorax. Condition (?). Duration 25 hours. Operation 5 hours later: Entrance wound excised; fractured rib resected. Hemothorax removed. Two holes in lower right lobe sutured. Foreign body removed from liver; hole in diaphragm sutured. Wound closed without wire rib stay. September 30, 1918: Aspirated; no fluid obtained. October 6, 1918: Wound ruptured; seropurulent fluid escaped. Tube inserted; end covered with gutta-percha valve. October 18, 1918: Evacuated in good condition. Lung expansion excellent.

Sucking wound, 30 hours old; bile in pleural cavity; all indicated primary drainage. Rupture of incision from within of wound closed without rib stay indicates the value of that suture.

33. M. L. September 28, 1918: Bullet, through-and-through wound, right chest. Entrance, third rib, parasternal line; exit, costal margin, anterior axillary line from which bile was escaping. Condition poor. Duration 38 hours. Operation: Entrance wound ignored. Fractured sixth, seventh, and eighth ribs resected. Hemothorax evacuated. Holes in lung and diaphragm sutured. Drainage to liver wound. No notes on convalescence or at discharge. January 7, 1919: Small amount of fluid aspirated. August 28, 1921: Pain and dyspnea only after sharp exertion. Fibrous pleurisy. Diaphragm fixed. Costophrenic sulcus obliterated. Disability 20 per cent. Vital capacity 71 per cent.

This man's condition prevented complete operation. Had primary drainage been used with proper after care disability would have been less. Aspirated second day, yet fluid was withdrawn four months later. An example of slow absorption of effusions as well as the wisdom of operating even if there has been delay.

34. S. D. September 28, 1918: Bullet, through-and-through wound, left shoulder and chest. Entrance just to left of vertebra; exit, high in axilla. Condition very poor. Duration 23 hours. Operation: Seven hours later. Wounds excised; fractured second and third ribs resected. Laceration in lung repaired. Large hemothorax evacuated. Closure. Blood transfusion. Died in one hour.

Earlier operation would have been effective. Other risks quite as forbidding had recovered.

35. H. H. September 28, 1918: Bullet, through-and-through, both wounds sucking, left chest. Condition poor. Duration 36 hours. Operation: Resection sixth, seventh, and eighth ribs. Excision of splenized lung; suture of hole in pericardium; repair of laceration in diaphragm; evacuation of hemothorax. Closure. Five hundred c. c. gum salt for shock. Death in two hours. Necropsy: Small amount of blood in pericardium. Left lung partially collapsed. Splenization incompletely removed. (Exposure inadequate at operation.)

This man's death due to delay and exposure, as he could have been saved with early operation. Another example of the necessity to secure adequate exposure.

36. F. McC. September 29, 1918: Shell fragment, through-and-through, sucking wound, right chest. Entrance below sixth rib, anterior axillary line; exit over eleventh rib below scapula. Condition bad—cold and shocked. Duration 10 hours. Operation: Three hours later. Entrance wound not treated. Exit wound excised; fractured rib resected. Lower lobe lacerated; contained indriven rib fragments and was bleeding profusely. Fragments removed; sutured; chest closed tight. October 2, 1918: Wound opened spontaneously; discharged 300 c. c. turbid fluid containing streptococci. October 5, 1918: Dyspneic, cyanotic, delirious. Contralateral pneumonia. October 6, 1918: Died. Necropsy: Purulent bronchitis, right; fibrinous pleuritis, right; collapse and splenization of lung, right; massive bronchopneumonia, left; pericarditis; vegetative endocarditis; infarction of kidney.

Man's condition prevented extensive operation. The small chance there was was forfeited by failure to drain.

37. J. A. L. September 30, 1918: Shell fragment, penetrating wound, right chest. Entrance, seventh rib, posterior axillary line. Large hemothorax. Condition grave. Duration 55 hours. Operation: Five hours later. Wound excised. Perforated rib resected. Hemothorax evacuated. Much bile present. Foreign body in liver. Thick fibrinous pleuritic exudate. Liver tear repaired. Diaphragm sutured. Man too low to stand further operation. Peritonitis present. October 5, 1918: Homolateral bronchopneumonia. October 6, 1918: Died. Necropsy: One thousand three hundred c. c. fluid in chest; lung collapsed. Tract of projectile in liver led to large thrombosed vein. Foreign body found, covered with fibrin, lying between columnæ carneæ of right ventricle.

Lethal injury at time of operation after 60 hours. Early and more complete operation would have saved him.

38. O. W. September 30, 1918: Bullet, penetrating wound, sucking, right chest. Entrance, seventh interspace, posterior axillary line. Condition bad. Duration 66 hours. Operation four hours later: Entrance wound excised; fractured eighth, ninth, and tenth ribs resected. Pleural cavity cleaned and closed. October 4, 1918: Incision opened spontaneously. October 5, 1918: Died. Necropsy: Lower lobe collapsed except where splenized. Empyema. Wounded lung contained bone fragments.

Lethal injury at time of operation after 70 hours. Illustrated a common error. Operation should be sufficiently radical to give chance for recovery even at risk of death on table Early, complete operation would have saved.

39. C. K. October 14, 1918: Shell fragment, perforating wound, left chest. Entrance, eighth interspace, midaxillary line; exit, eighth interspace, midscapular line. Foreign body under skin. Moderate hemopneumothorax. Condition good. Duration 8½ hours. Operation: Excision of entrance wound. Fractured ninth rib resected. Bone fragments driven into diaphragm, which was repaired and sutured into defect to close pleura after evacuation of large hemothorax. Foreign body removed. 1921. Records available. Disability less than 10 per cent.

Early operation led to prompt recovery.

40. (German soldier.) October 12, 1918: Bullet wounds, right arm, and penetrating, right chest. Entrance over tenth rib, posteriorly. Condition poor. Duration 54 hours. Operation: Amputation arm; gas gangrene. Excision of entrance wound; resection fractured tenth rib. Repair of lacerated diaphragm. Evacuation of hemothorax. Closure. Death within a few hours.

Injury lethal at time of operation.

41. H. C. October 15, 1918: Shell fragment, sucking, penetrating wound, right chest. Entrance, third rib, high in axilla. Condition poor. Duration 28½ hours. Resuscitation 7½ hours. Operation: Entrance wound excised; fractured third rib resected. Old pleuritic adhesions and patient's condition made radical operation impossible. Foreign body in upper lobe not sought. Hole in lung sutured. Gauze drain. October 29, 1918: Died. Necropsy: Abscess in lung and liver.

Rare instance of abscess forming about foreign body. Hole in lung should have been left open. Fear of bronchial fistula is not well founded.

42. W. L. October 15, 1918: Shell fragment (1 by 1.2 cm.), penetrating wound, right chest. Entrance through middle of clavicle; lodgment in right, upper lobe. Condition poor. Duration 22 hours. Operation three hours later: Entrance wound excised; comminuted fractures of clavicle, first and second ribs resected; fragments removed from lung. Lung repaired. Hemothorax evacuated. Pleural defect closed with muscle. Died during night; cause unknown. No necropsy.

Severe injury made lethal by exposure and delay.

43. L. B. October 15, 1918: Bullet, through-and-through, sucking wound, left chest. Entrance just above left nipple; exit, ninth rib, paravertebral line. Moderate hemothorax. Condition poor. Duration 24 hours. Operation: Entrance wound not treated. Exit wound excised; fractured ninth rib resected; wound in lower lobe sutured; pleura closed; no drainage. October 16, 1918: Died. Cause of death probably shock.

Another moderately severe injury made lethal by exposure and delay.

44. J. K. November 1, 1918: Bullet, through-and-through, sucking (exit) wound, right chest. Entrance in anterior axillary fold; exit above eighth rib, paravertebral space. Small hemopneumothorax. Condition (?). Duration 11 hours. Operation one and one-half hours later: Wound of entrance untreated as it was found to be smooth on inside. Exit wound excised. Fractured eighth rib resected. Liquid and clotted blood removed. Wounds of entrance and exit in lower lobe sutured. Wounds in upper lobe not found. Parietal pleura closed fairly accurately with aid of one wire rib stay. November 16, 1918: Convalescence stormy. Despite aspiration, wound broke down from within with spontaneous discharge of pyothorax. Had asthmatic attacks. Returned to duty in 90 days. Disability (estimated) 10 per cent.

Imperfect closure of parietal pleura is always a source of danger. Fortunately, this rupture occurred after adhesions had formed so that collapse was obviated. Primary drainage was indicated.

45. A. R. November 2, 1918: Bullet, through-and-through wound, left chest. Entrance, fifth interspace, posterior axillary line; exit, ninth rib, midscapular line. Slight interstitial emphysema about exit wound. Fluoroscope revealed moderate hemopneumothorax; fracture of ninth rib and involvement of left lower lobe. Condition fair. Duration 11 hours. Operation: Exit wound excised; shattered rib resected; pleura opened widely; many rib fragments removed. Splenized and lacerated lower lobe resected and sutured after evacuation of hemothorax. Wound of entrance found on internal examination to be smooth so not disturbed. One wire rib stay. Pleural closure incompleted so reinforced with muscle. November 8, 1918: Uneventful recovery. Wire rib stay removed. November 11, 1918: Evacuated in excellent condition. No further records obtainable. Disability estimated at 10 per cent.

Treatment here was good. Illustrates the wisdom of attacking worst wound first and thoroughly, and letting the internal examination determine whether any further operation is needed. Early removal of wire rib stay was beneficial. Resection of injured lung assured recovery. Primary drainage had been safer because pleural closure was inadequate and pyothorax would likely have led to spontaneous opening.

46. F. K. November 2, 1918: Multiple wounds; shell fragments, one, through-and-through, three penetrating right chest; one bullet, penetrating abdomen. Chest wound sucking and emphysematous. Condition poor. Duration unknown. Prolonged resuscitation. November 3, 1918: Operation: Exit wound over ninth rib excised and fractured rib resected. Wounds in lower lobe sutured. Two wounds in diaphragm sutured to excluded herniated and wounded liver, in which foreign body was not sought because of patient's condition. Bile-stained hemothorax evacuated. Drained with tube armed with flap valve obtained from gas mask. Fair approximation of pleura. Skin closure not attempted because of empyema. November 4, 1918: Died in spite of attempts at resuscitation. Necropsy: Valve drain had functioned perfectly. Wounded lung inflated notwithstanding pulmonary edema. Bullet found in retroperitoneal tissues, only injury to kidney. Death due to myocardial incompetence.

Severe multiple injuries with cold and exposure made condition lethal by time of admission to hospital. Recovery with early operation possible. Operative treatment good.

47. J. R. A. November 2, 1918: Shell fragment, through-and-through, left chest. Entrance, third interspace, nipple line; exit, seventh rib, posterior axillary line. Wounds dirty. Condition serious. Duration 27 hours. November 3, 1918: Operation: Both wounds excised. Fractured rib at exit resected. Bone fragments in lung. Four injuries repaired. Liquid and clotted hemothorax (800 c. c.) removed. Both pleural reflections hemorrhagic. Entrance wound on inner aspect not examined. Pleural closure satisfactory. Operation hastened and terminated by patient's condition. November 5, 1918: Never regained strength. Seven hundred and fifty c. c. thin, bloody fluid aspirated. Streptococcus (?). Cyanosis and dyspnea. Died. Necropsy: Left chest contained 500 c. c. thin, bloody fluid. Fibrinous pleurisy. Pericarditis with effusion. Acute dilatation of right heart; pulmonary edema. Fracture of fourth rib at entrance wound.

Wounds, not of themselves lethal, had become so through cold and delay. Recovery was easily attainable with early operation. Drainage should have been employed, but could not have altered, merely postponed, the outcome.

48. J. C. November 2, 1918; Bullet wound, through-and-through, right chest. Entrance, sixth interspace, midaxillary line; exit, twelfth rib, paravertebral line. Moderate hemothorax. Mitral insufficiency. Dirty wounds. Condition poor. Duration 46½ hours. Operation: Entrance wound excised; no rib injury. Exit wound excised; fractured eleventh rib resected. Large hemothorax removed. Laceration in diaphragm and upper pole of kidney repaired. Lung inflated and laceration repaired. Pleura closed tight. Gutta-percha drain to kidney and liver. November 7, 1918: Developed jaundice, edema of extremities and pleuritic effusion. Died. Necropsy: Large pleuritic effusion. One laceration in diaphragm had been overlooked. Acute diffuse hepatitis. Liver wounds necrotic. Acute fibrinous pericarditis.

Another reparable injury made fatal by delay. Line far in advance and transportation of wounded almost impossible. Drainage should have been employed.

49. A. D. November 4, 1918: Bullet, through-and-through wound, left chest. Entrance above left clavicle; exit, ninth rib, paravertebral line. Large hematoma at entrance wound. Left radial pulse absent. Condition poor. Duration (?). Operation:

Wound of exit excised and fractured ninth rib resected when patient stopped breathing. Oxygen had given out. Injection of adrenalin into heart and direct massage started cardiac contractions. Incision closed. Death in two and one-half hours. Necropsy: Hematoma at entrance wound and absent radial pulse due to section of subclavian artery.

Positive pressure analgesia too rich in nitrous oxide when oxygen supply failed. Cardiac resuscitation not prompt enough to save central nervous system from fatal degeneration. Man was probably lethally injured.

SUMMARY OF GROUP III

Operations, called thoracotomies of necessity, were performed upon 49, or approximately 55 per cent of the series. Included are many of the most serious wounds, thus treated because more ideal methods were impossible notwithstanding the exposures obtained were inadequate for deep repair.

Fatalities.—There were 22 deaths, mortality rate of 45 per cent. It is noteworthy that the mortality rate in the first half of the series is 32 per cent and in the second 58 per cent despite the fact that after greater experience the later treatments were better. The difference is due to the colder weather, rain, and greater difficulties in transportation.

One-half of the deaths occurred within 24 hours after operation. One (1) was due to acute anemia and could have been avoided with multiple transfusions; one (11) was due to too high positive pressures; one (49) to too high concentration of nitrous oxide (failure of oxygen supply) in the administration of analgesia. Four (6, 12, 14, 46) had received injuries sufficiently serious to cause death even if treated promptly. Operation was performed 10, 56, 5, and 24 hours after injury; average 26 hours. Five (34, 35, 40, 42, 43) had received injuries not severe enough to jeopardize life if promptly relieved, but were rendered lethal by exposure and delay. Operation was performed 30, 36, 54, 25, and 24 hours after injury; average 33 hours.

Two (20, 47) of the half of deaths that occurred more than 24 hours after operation took place within 3 days. One (20), within two days, was lethally injured, the other (47), within three days, had become fatally affected by delay. The balance (7, 8, 31, 36, 38, 39, 41, 48) survived operation from 5 to 14 days. Five developed pyothorax (7, 8, 31, 36, 38), which was due to incomplete operation, e. g., failure to excise splenized lung (38), to close a bronchial fistula (31), the only one in the series, and to institute primary drainage. The average duration before operation was 34 hours. One (37) died because a shell fragment that had not been removed from a liver was transported to the heart and contributed to a fatal septicemia. Another shell fragment not removed from a liver (42) caused a fatal acute hepatitis. A shell fragment in a lung (41) caused a lung abscess because the track was sutured; this was the only lung abscess noted.

Four deaths were caused by obvious surgical errors—a failure to transfuse (1), too high pressures with administration of anesthetic (11), too high concentration of anesthetic (49), and suturing instead of draining the tract of a foreign body in an adherent lung (41).

Five deaths which occurred in the second half (31, 36, 37, 38, 48) were operated upon on the average of 43 hours after injury. None were given the benefits of a

complete operation, yet they survived on the average one week. Operation was hurried and unfinished in each instance because condition of the individuals was so poor. Hindsight seems to teach that one or two might have survived, if at the cost of greater immediate risk an opportunity for ultimate recovery had been provided. Mortality chargeable to surgical errors and accidents (limited supply of blood for transfusions, exhaustion of supply of oxygen, use of too great positive pressure in analgesia, closure of tract in lung, failure to complete operations in spite of impending death and to use primary drainage) is 13 per cent.

Disabilities.—Late disability ratings are available for 23 of the 25 survivors. Two were zero (5, 25); six less than 10 per cent (15, 18, 22, 24, 26, 39); four at 10 per cent (2, 21, 44, 45); two at 15 per cent (10, 19); two at 20 per cent (27, 28); two at 35 per cent (4, 16); one at 40 per cent (3); 75 per cent (17); 80 per cent (13); and 100 per cent (29). Two ratings are low (25, 27) and five are high (4, 13, 17, 28, 29) as shown by physical examination, fluoroscopy, resistance exercises and estimations of vital capacity.

According to the figures the average disability was 21 per cent. This is higher than the facts would justify, but is accepted to be safe. Only four were returned to duty, 2 in 90 days (15, 39) and 2 in 180 days (2, 24), giving an average of 135 days, which also is too high, but may be accepted as a safe estimate.

Pleuritis remains a constant factor in producing disability, but there is added, because of the increased severity of injuries, greater interference with parietal integrity, notable in multiple rib injuries, more frequent diaphragmatic lacerations, and greater destruction of lung tissue requiring resections. Likewise more complicating lesions appear—liver, kidney, pericardium, and peritoneum. A disability rating even of 21 per cent is not entirely discreditable when it be considered that the average duration before operation was 19 hours and that none of these men received proper after-care. The evil effects of preoperative delay in the more serious injuries is apparent. Those who recovered with disabilities of 20 per cent or less were operated upon in 15 hours on the average; those above 20 per cent in 27 hours.

It was noted above in discussing fatalities that more finished operations and more frequent use of drainage would have reduced the mortality rate. The same applies even more directly to reductions in duration and extent of disabilities because sucking wounds are common, soiling of pleura with bile is frequent, and with urine is occasional. The need for better immediate and continued after-care is self-evident.

DEDUCTIONS

Thoracotomies of necessity will be performed upon the less severely injured when parietal excisions and limited thoracotomies reveal unexpected lesions that require more radical immediate intervention and upon those so severely injured that parietal and deep repair must be made through one opening. Advantages are the greater rapidity, avoiding making a separate incision and thus not impairing parietal integrity by surgical wounds added to the projectile destruction. Disadvantages are the frequent failures to obtain satisfactory exposure to make proper intrathoracic repair and the temptation

to avoid risks of operative deaths by performing incomplete operations when finished operations are needed to obtain ultimate recoveries.

CONCLUSIONS

Operations of this type will inevitably be more frequent than other serious procedures and demand greater consideration. Improved facilities in advance of mobile hospitals and the establishment of a thoracic surgical division would make better methods possible. If the thoracic wounded were provided with proper treatment from front to base, not only could the less severely injured be shunted to hospitals farther toward the rear when the fighting is active, but the more severely injured could be evacuated earlier. This might well provide for two-stage operations that would secure recoveries in types that now seem to be almost hopeless.

The need for more effective prevention and treatment of shock which includes promptness as a first requisite as well as continued and consecutive care under unified control is indisputable. Simplifying and perfecting the technical details appear now to be easy. The combination is desirable and attainable. Returns to active duty were few and delayed.

GROUP IV. THORACOTOMY OF ELECTION

1. F. P. July 30, 1918: Shell fragment, penetrating wound, left chest. Entrance, left sternoclavicular articulation; foreign body lodged in lower lobe. Large hemothorax. Heart displaced to right. Condition (?). Duration (unknown). Operation: Entrance wound excised; sternum resected; pleural defect closed with muscle. Fourth rib resected. Hemothorax evacuated. Lacerated lung repaired. Hematoma in lung and foreign body not removed. Wire rib stay. Layer closure. No drainage. Postoperative interstitial emphysema from wound of entrance. Moderate pleuritic effusion. Later was operated upon at a base hospital, anterior and posterior drainage for empyema. May 19, 1919: Drained again at Walter Reed Hospital and wire stay removed. November 14, 1919: Discharged. July 28, 1921: Dyspnea and pain on exertion. Deficient expansion, multiple parietal scars, chronic pleuritis, immobile diaphragm, heart displaced to left, cardiac competence fair. Disability 50 per cent. Vital capacity 58 per cent.

This an early experience; battle rush; no assistant. Operation incomplete. Foreign body should have been removed and intrapulmonary hematoma evacuated. This with drainage would have prevented empyema. Proper after-care would have reduced disability at least by half. Rib stay should have been removed early.

2. D. July 31, 1918: Shell fragment, penetrating wound, left chest. Entrance wound over (?) rib, foreign body in upper lobe. Moderate hemothorax. Condition (?). Duration (unknown). Operation: Entrance wound excised; fractured rib resected; pleural defect closed. Thoracotomy at site of election. Hemothorax evacuated. Foreign body removed. Lung repaired. Wire rib stay. Layer closure. No drain. August 3, 1918: Limited pleuritic effusion. Continued improvement. Lost.

Notes too meager for any judgment.

3. A. L. B. August 8, 1918: Shell fragments, left arm, shoulder, leg, penetrating left chest, which contained two foreign bodies. Entrance over fourth rib, axilla. Large hemothorax. Condition (?). Duration 18 hours. Operation: Foreign bodies removed from leg, elbow and shoulder. Entrance wound excised; fractured fourth rib resected; thoracotomy at site of election. Large hemothorax evacuated. Lacerations in upper lobe

repaired. No note of foreign bodies. Two wire rib stays failed to provide satisfactory closure at anterior angle. No drainage. August 10, 1918: Much interstitial emphysema from incomplete closure. August 13, 1918: Chill. Increased pleuritic effusion; 650 c.c. blood-stained fluid aspirated. August 16, 1918: Fluid reaccumulating. Aspirated and found to contain much fibrin. Rib resection and open drainage. August 17, 1918: Subsequent progress excellent. Disability for seven months. Ultimate disability 15 per cent (estimated).

Primary drainage would have hastened recovery and reduced disability.

4. W. S. August 9, 1918: Shell fragment, perforating, right chest; entrance wound, posterior axillary line at level of angle of scapula; foreign body lodged in mediastinum posterior to aorta. Enormous hemothorax. Condition bad. Duration eight hours. Operation: Thoracotomy at site of election to give immediate opportunity to check bleeding because of severe and increasing acute anemia. Injured azygos vein found and ligated with great difficulty. Death occurred as bleeding laceration in upper lobe was being sutured.

Hemostasis imperative but attempted too late even at eight hours. Transfusions might have been effective. A serious and usually fatal injury.

5. M. B. August 11, 1918: Shell fragment, through-and-through wound, lower left chest. Large hemothorax. Burns to head and face. Both ear drums ruptured from shell explosion. Condition bad. Blood pressures 90/50. Duration six hours. Resuscitation attempted; pulse became barely perceptible. Chance of any recovery lay in immediate hemostasis. Operation: Thoracotomy at site of election to expose bleeding points surely and with least delay. Lacerations in lower lobe sutured. Death from acute dilatation of right heart.

Injuries lethal at time of operation. Questionable if earlier intervention could have succeeded.

6. L. G. September 12, 1918: Bullet, perforating wound, left chest. Entrance wound, second interspace below middle of clavicle. Foreign body under skin below angle of scapula. Large hemothorax. Free hemoptysis. Heart widely displaced. Interstitial emphysema more prominent posteriorly. Condition (?). Duration unknown. Operation: Entrance wound excised. No rib damage. Closed. Bullet removed. No rib damage. Closure. Thoracotomy at site of election. Hemothorax evacuated. Wounds in upper lobe sutured. Entrance wound surrounded by zone of splenization which was not excised. One wire rib stay. Layer closure. Superficial drain. September 13, 1918: Greater emphysema about entrance and exit wounds because closure had not been effective. Good condition. September 16, 1918: Aspiration of sterile, pleuritic effusion. Continues to improve. Five months later he developed empyema and was treated by open drainage. Notes on present condition not obtainable.

Imperfect closures of entrance and exit wounds was poor surgery. Splenized lung should have been excised. Note the late empyema. Phrenic nerve should have been blocked.

7. J. J. M. September 12, 1918: Shell fragment, penetrating, left chest. Entrance, sixth interspace midaxillary line. Foreign body lodged near heart, moving with each contraction. Moderate hemopneumothorax. Heart slightly displaced. Condition good. Duration five hours. Operation: Six hours later: Entrance wound excised. No rib damage. Pleural defect plugged with muscle. Fourth rib resected, hemothorax evacuated. Wounds in upper and lower lobes sutured. Foreign body at hilum, close to pulmonary artery and not removed for fear of injuring vessel. Phrenic nerve blocked with 1 per cent cocaine. September 14, 1918: Interstitial emphysema from wound of entrance. Considerable pleuritic effusion. Diaphragm on left side seen with fluoroscope to be in extraordinarily high position. September 17, 1918: Exceptionally comfortable convalescence but usual

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amount of pleuritic effusion. Absorption of fluid not noticeably favored by diaphragmatic paralysis. Diaphragm now crowded into low position by fluid. September 18, 1918: Six hundred and fifty cubic centimeters fluid aspirated, contained cocci in pairs and chains. December 18, 1918: Discharged from service. Disability 15 per cent.

Foreign body should have been removed as immediate risks are less than ultimate dangers. Plugging of pleural defects with muscle again unsatisfactory. In this instance the visceral pleura might have been sutured to the parietal at close of operation. Comforts of phrenic nerve block demonstrated. Effusion due rather to bacterial irritation than to faulty absorption. Primary catheter drainage would have been safer and hastened recovery.

8. H. G. (German soldier). September 13, 1918: Shell fragments, multiple injuries to right chest and arm. Entrance to chest over fourth rib laterally. Large foreign body 0.3 by 3.5 cm. deep in chest. Right diaphragm unaffected. Moderate hemothorax. Subcutaneous emphysema. Condition poor. Duration unknown. Operation: Arm wound excised and foreign bodies removed. Wound of entrance excised. Many foreign bodies, including bits of clothing, removed. Fractured fourth rib resected. Hemothorax evacuated. Upper lobe not exposed because of old adhesions. Bleeding had ceased. No note of removal of foreign body. Collasped lower lobe was inflated nearly to normal. Good closure obtained with one wire rib stay. Postoperative shock. Systolic pressures were raised from 60 to 90 with 600 c. c. gum salt intravenously. September 20, 1918: Evacuated in good condition. Two aspirations and opening of focus of suppuration in superficial wound.

Man's poor condition precluded completed operation. Superficial wound, because of emphysema, should have been drained. Proof that inflatable lung is trustworthy.

9. N. P. (German soldier). September 13, 1918: Shell fragment, through-and-through, left chest. Entrance at angle of scapula; exit, above scapula. Moderate hemothorax. Left diaphragm moves one-half as widely as right. Condition (?). Duration unknown. Operation: Entrance wound excised. Fractured scapula and fourth rib resected. Tunnel wound in upper lobe resected and sutured. Exit wound above scapula resected. Closure with one wire rib stay. September 17, 1918: Uncomfortable. Some residual pneumothorax and pleuritic effusion. September 21, 1918: Conditions little changed. Evacuated.

Lung repair imperfect else no pneumothorax. Serious injuries warranted primary drainage.

10. G. A. September 14, 1918: Shell fragment, penetrating, left chest. Entrance over second rib below middle of clavicle. Foreign body, 3 by 0.7 cm. substernal and deflected with each heart beat. Large hemothorax clouding left chest. Heart displaced to right. Very dyspneic. Condition fair. Duration seven hours. Operation: After five hours' resuscitation: Entrance wound excised. Thorax opened by resecting fourth rib. Hemothorax, 600 c. c., evacuated. Perforations in lower margin of upper lobe repaired. The exit wound in lung revealed by escaping air with positive pressure. Foreign body removed from contact with aorta. Closure with one wire rib stay. Condition good. September 17, 1918: Very uncomfortable. Two hundred centimeters dark bloody fluid aspirated. No bacteria found. September 21, 1918: Small pleuritic effusion persists. Disabled for 180 days. No other information. Estimated disability 15 per cent.

Primary drainage. Phrenic block and exercises would have been wiser.

11. F. J. C. September 18, 1918: Shell fragments (grenade) right hip, through back and chest. Entrance wound not found. Foreign body in right lung, seven cm. in diameter. Pleural cavity obscured. Diaphragm immobile. Heart displaced to left. Condition (?). Duration 12 hours. Operation: Superficial wounds excised and foreign bodies

removed. Entrance wound to chest not found. Thoracotomy at site of election; 2,000 c. c. of bloody fluid evacuated, little clotting. Long, edematous laceration, posterior aspect right lower lobe resected and sutured. Multiple areas of contused lung. Foreign body not found. Pleural closure perfect. One wire rib stay. Preoperative blood pressures, 115/94. Postoperative blood pressures, 100/94. Six hours later systolic pressures suddenly fell to 60. Seven hundred cubic centimeters gum salt elevated pressures to 78/50. In 45 minutes they fell to 56/40. Transfused 600 c. c. citrated blood; rose to 88/60, where they remained for two hours, then sudden collapse and death. Necropsy: Repair of both pleuræ is good. Small area of splenization in lower right. Wound of entrance to chest posteriorly from two injured vertebræ. Small hemothorax. Serofibrinous pleurisy. Death explained neither by anatomic lesion nor operative procedure. Attributed to medullary anemia.

Operation alone could have led to recovery. Multiple and large transfusions required to rehabilitate circulation.

12. J. L. September 27, 1918: Bullet, perforating, right chest. Entrance through back of neck; bullet lying beneath skin over eighth rib lateral to scapula. Condition poor. Duration 53 hours. Operation after five hours' resuscitation: Entrance wound in neck not disturbed. Incision over eighth rib; evacuation of hematoma; removal of foreign body; resection of fractured rib (eighth). Pleural closure. Thoracotomy at site of election. Large hemothorax evacuated. Splenized gutter wound with bronchial fistula in lower lobe excised. One rib stay. Layer closure. October 4, 1918: Aspirated fluid containing many streptococci. Chest drained. Local anesthesia. October 8, 1918: Evacuated. Condition bad. October 13, 1918: Died. Septicemia. No necropsy.

Severe wound, long duration, bronchial fistula, feeble patient. Should have been drained at operation. No less complete operation would have provided opportunity for recovery.

13. A. B. R. September 30, 1918: Bullet, penetrating, left chest. Entrance at left costovertebral angle. Foreign body lodged beneath left clavicle and moves with each heart beat. Dyspneic though hemothorax is small. Condition fairly good. Duration 24 hours. Operation: Entrance wound excised. Fractured twelfth rib resected. Pleural closure. Thoracotomy at site of election; 500 c. c. bloody fluid aspirated. Two holes in lower lobe and one hole in upper lobe sutured. Bullet removed from left apex. One wire rib stay. Layer closure. No drainage. October 6, 1918: Smooth convalescence. Small effusion. July 10, 1919: Wire rib stay removed. Graduated exercises begun, which were beneficial even at this late date. September 14, 1919: Discharged from service. July 26, 1921: Below normal weight; lacks endurance. Fibrous pleuritis. Obliteration of costophrenic sinus. Defective expansion. Disability of 30 per cent is low. Vital capacity 71 per cent.

Early and continued breathing exercises would have reduced disability. Wire rib stay should have been removed promptly.

14. P. McG. October 10, 1918: Bullet, penetrating, right chest. Entrance outer one-third of right clavicle. Foreign body in liver. Interstitial emphysema. Moderate hemothorax. Heart displaced to left. Three lobes of lung perforated. Condition poor. Duration eight hours. Operation: After three and one-half hours' resuscitation: Entrance wound not touched. Thoracotomy at site of election. Inner aspect of entrance wound smooth. Wound at apex of lung could not be exposed. Three tears in lung repaired. Hemothorax evacuated. Bullet could not be felt in liver. Hole in diaphragm sutured. Layer closure. One wire rib stay. Superficial wound of entrance excised and drained because of emphysema. During convalescence developed empyema which was drained and wire stay removed. February 1, 1919: Drainage ceased. August 11, 1921: Dyspnea after sharp exertion. General condition good. Chronic adhesive pleuritis at right base limits excursions of diaphragm. Disability, 22½ per cent. Vital capacity, 96 per cent.

Primary drainage indicated, particularly by liver injury. Proper exercises would have reduced duration and extent of disability which is due to pyothorax. Bullet in liver is not harmful.

15. W. B. November 2, 1918: Bullet wounds, penetrating right arm and through-and-through, right chest. Entrance, sternoclavicular joint; exit, sucking at right anterior axillary fold. Hemothorax slight. Pneumothorax large. Provisional sutures in exit wound showed this to have been a "sucker." Foreign body in right forearm. Operation: Wound in forearm excised and bullet removed. Wound of exit excised; compound fracture of fourth rib resected and chest opened; 60 c. c. fluid blood and no clots evacuated. Focus of splenization at extreme tip of middle lobe and adjacent triangle of upper lobe. No lung operation. (Patient probably in critical condition.) Wire rib stay. Layer closure. Defect in parietal pleura reinforced with muscle. November 17, 1918: Stormy convalescence after good immediate recovery. Finally a pyothorax developed containing anaerobes and streptococci. Rib resection and drainage. Continued improvement. Ultimate result unknown.

Incomplete operation, probably because of patient's condition, not justified. If it were, leaving splenized lung assured pyothorax and demanded primary drainage.

16. R. B. November 5, 1918: Shell fragment, through-and-through wound, right arm, penetrating wound, right chest. Entrance, anterior axillary line over fourth rib. Foreign body (0.8 by 1 cm.) resting on diaphragm. Moderate hemothorax. Cold and severely shocked. Duration unknown. November 6, 1918: Continued hemoptysis. Fair recovery from shock. Blood pressures 110/82. Operation: Entrance wound and fractured fifth rib resected; 120 c. c. liquid and 1,200 c. c. clotted blood removed. Foreign body removed. Two holes in middle lobe sutured. Wound in lower lobe not found because old adhesions prevented exposure. Wound in forearm excised. November 8, 1918: Exploratory aspiration, putrid fluid. Local anesthesia. Rib resection. Insertion of air-tight glass tube armed with check valve. November 16, 1918: Evacuated in good condition. Little pneumothorax. Still draining. No further record.

Wound of long duration, weak patient, chronic pleurisy—all demanded primary drainage, which could have been effective in preventing pyothorax.

SUMMARY OF GROUP IV

Thoracotomies for the repair of intrathoracic lesions were performed at the sites of election, i. e., through the middle portions of the fourth or fifth rib upon 16 patients, 15 per cent of the entire series. The injuries were serious enough to require prompt attention and permitted or demanded wide exposure so that repair of all lesions might be possible immediately.

Fatalities.—There were four deaths, a mortality of 25 per cent. Three (4, 5, 11) of the four deaths occurred within six hours; two (4, 5) during operation. Each was in critical condition, each suffering from acute anemia or exemia, and in each it was essential to secure prompt hemostasis for which thoracotomy of election offers largest opportunities. The 4th (12) lived 16 days, dying of septicemia from pyothorax which primary drainage might have prevented. Mortality chargeable to surgical shortcomings is 6 per cent. Operations were performed 8, 6, 12, and 58 hours after injury, average 21 hours. It is noteworthy that the one who lived the longest and who might have recovered is the one (12) whose wound was of the longest duration.

Disabilities.—Late ratings are available for only 6 of the 12 survivors. Three (3, 7, 10) at 15 per cent; one (14) at 22½ per cent; one (13) at 30 per cent; and

one (1) at 50 per cent, giving an average of 20 per cent. Six (2, 6, 8, 9, 15, 16) are not estimated. Two were returned to duty (10, 3) in 180 and 210 days, average 195 days' duration of convalescence. The average late disability (20 per cent) and duration of immediate disability (195 days) are obtained from insufficient data to be reliable but as both are high they are accepted as safe.

Pleuritis is the chief cause of disabilities as the parietal destructions and lung lesions are less severe than those in Group III and there were fewer complicating injuries. Pleuritis was the cause of immediate distress to all but two (2, 13); six (1, 3, 6, 14, 15, 16) developed pyothorax which had to be drained; four (7, 8, 9, 10) were aspirated one or more times. The average duration of wounds prior to operation was 16 hours for those who recovered and 21 hours for those who died. The wounds in the men who received less than the average disability rating of 20 per cent had been of 13 hours' duration; in those above 20 per cent, 18 hours; in those who developed empyema, 20 hours. The evil effects of delay are again illustrated; likewise repetitions of indications for primary drainage, notably in duration of injury.

An average disability rate of 20 per cent will not reflect upon the nature of thoracotomy of election when it is recognized that 50 per cent of the survivors developed pyothorax because of failure to employ primary drainage and that only one (13) received any nonsurgical after-care. Disabilities from pyothorax alone usually exceed 40 per cent. Breathing exercises, though delayed for months, benefited one patient materially. Again it is evident in this group that more finished operations and the use of drainage, in brief, more radical treatment, would have reduced both mortality and morbidity rates. Likewise earlier treatment promises better results than later. Blocking the phrenic nerve should have been a routine. It was not done often enough to prove or to disprove its apparent aid to defense. Reduction in discomfort alone warrants its use.

DEDUCTIONS

Thoracotomies of election will be performed more frequently as their value is demonstrated by the better results obtained when more radical measures are employed. They can be used most effectively in the following varieties of wounds: When immediate hemostasis is required, the lesion deep-seated and a generous exposure of all possible sources of hemorrhage must be obtained by the shortest and surest approach; when the nature and location of injury make a thoracotomy of necessity coincide with the site of a thoractomy of election; when the exposures obtained by parietal excisions or attempted limited thoracotomies, and the condition of the patient warrant employment of the most adequate means to effect deep repair. The advantages of being enabled to examine the entire side of a chest and to effect all repair possible in intrathoracic procedures are sufficient to compensate for certain disadvantages. These are the occasional occurrence of chronic pleuritic adhesions sufficient to make pulmonary mobilization impracticable, the additional impairment of parietal integrity and more prolonged operations. Pleuritic adhesions occur so infrequently in soldiers as to be an almost negligible handicap. A few observations indicate that the parietal injuries occasioned by thoracotomy of election performed even with rib resection, if properly treated subsequently, will not

add appreciably to disability. Moreover, it is probable that the provision of suitable primary drainage with consequently lessened dangers of pyothorax will justify intercostal thoracotomy unless rib fractures are present. Important as the time factor may be in operating upon seriously distressed patients, the other factors of better work done with less added handicaps of limited exposure often obtained with harmful traction make slightly more prolonged operations the safer.

CONCLUSIONS

Thoracotomies of election will prove more serviceable now that principles are better understood, means for primary drainage are at hand, and technical abilities in intrathoracic operations are developing widely and rapidly. Indeed, it is reasonable to predict that improvement in operative procedures coupled with more competent care of the wounded will show that reductions in both mortality and morbidity rates will be such that even the less seriously wounded, having more than limited hemothorax, will be better served by thoracotomy. Thoracotomy of election would be the method

Returns to active duty were few and long delayed. There was no suitable after-care and the need for replacements never became acute in our Army. It is perhaps idle to guess what might have been accomplished. Few, indeed, of the wounded, who will be fit again for duty, will require more than 90 days for recovery, which must be within 10 per cent or 15 per cent of normal. Smooth healing and suitable after-care would make such recoveries from thoracotomy of election the rule rather than the exception.

SUMMARY FOR ENTIRE SERIES

It is desirable to learn from all failures, ignorance of proper methods, lack of facilities for ideal care, faulty organization and administration and the like, the remedies that will assure better protection of the wounded hereafter.

FATALITIES

The following table correlates the essential facts.

	Group I		Group II		Group III		Group IV		Totals	
	Parietal excisions	Percentage	Limited thoracotomy	Percentage	Thoracotomy of necessity	Percentage	Thoracotomy of election	Percentage	All groups	Percentage
Patients	18	17	21	20	49	48	16	15	104	100
Deaths	4	22	8	38	22	45	4	25	38	37
Deaths from injuries initially lethal	1	25	1	13	4	18	0	0	6	16
Deaths from injuries made lethal by delay, etc	2	50	4	50	5	23	3	75	14	37
Deaths from therapeutic failures	1	25	3	38	13	32	1	25	18	47
Deaths from operative errors	1	5	3	15	7	13	1	5	12	10

A mortality rate of 37 per cent will appear to be woefully high until it be noted that 53 per cent of the deaths resulted from injuries initially lethal or made so by delay, hemorrhage, infection and exposure. The 18 remaining deaths are charged to therapeutic failures which include not only operative mistakes but also lack of adequate supplies of blood for transfusion, of hyper-

tonic glucose solutions, and insulin, failure to employ the intravenous administration of digitalis, and proper immediate and remote after-care. In other words 47 per cent of the deaths might have been reduced had materials and methods now available been used. Operations have been held entirely responsible for 12 deaths (10 per cent for the series and 30 per cent of the fatalities) inasmuch as this number survived long enough to die from complications which more exact methods could have obviated. The incompleted operations were not finished because the patients were in such critical condition that continuation appeared to be unwise, yet survival for several days is assumed to prove such conclusions to have been erroneous.

Criticism will be directed at the large proportion (53 per cent) classed as lethally affected who were subjected to operation. In some of these patients the fatal involvement was not recognized and could not have been recognized until exposures obtained by operation revealed irrecoverable lesions. Other men apparently equally or even more severely handicapped made excellent recoveries. Errors in judgment were numerous and because decisions must be made promptly without full information they will always be frequent.

The orders of the chief consultant, surgical services, A. E. F., to operate on every man who had the least chance for recovery, were proved to have been based upon sound surgical judgment as well as upon a high conception of obligation. A few of the men who died during or soon after operation conceivably might have survived without operation or had the operation been less exact. There was no proof of this. In several instances, postoperative blood transfusions would have averted death, but this was too often impossible because donors were not available. As experience grew and methods became more radical, the results improved. In retrospect, our regrets are that supposed conservatism allowed us to evade the responsibility of performing forbidding but necessary operations and thus to deny some men their only chance to survive.

DISABILITIES:

Interpretation of the causes of disability is most important. It will determine the chief factors in producing death, the greatest disability, as well as show how more complete recoveries could have been hastened.

	Group I		Group II		Group III		Group IV		Totals	
	Parietal excisions	Percentage	Limited thoracotomy	Percentage	Thoracotomy of necessity	Percentage	Thoracotomy of election	Percentage	All groups	Percentage
Patients	18	17	21	20	49	48	16	15	104	100
Recoveries	14	77	13	62	27	55	12	75	66	63
Disabilities:										
Unknown	1	7	2	15	2	7	6	50	11	17
Known or estimated	13	93	11	85	25	93	6	50	55	83
Average	--------	10	--------	13	--------	21	--------	20	--------	16
Number due in part to defects, surgically irreparable	1	7	1	8	11	40	3	25	16	23
Number due in part to therapeutic failures to remedy pleuritis	6	43	5	39	17	63	12	66	40	60
Number due in part to operative failures to restrict pleuritis	5	28	4	32	13	50	10	96	32	50
Average duration (days) of immediate disability	90	--------	100	--------	135	--------	195	--------	130	--------

Disabilities due in part to irreparable defects include destruction of parietes, costal and diaphragmatic, or such costal lesions as required the use of the diaphragm in effecting closure, cardiac lesions and injuries ordinarily remediable but not repaired because conditions prevented finished operations. These and the following estimates are based upon the results actually obtained and not upon what might have been done in the light of present knowledge.

Therapeutic failures consist mainly of omissions of postoperative aspirations and transfusions which would have favored defense and repair. They are by no means to be charged to ignorance and neglect since it was frequently impossible to give desirable individual attention and donors were often not to be had when most needed. No account has been taken of the failure to provide suitable exercises to aid in reestablishing the conditions for normal respiration. There is record of but one instance (Group IV, 3) in which breathing exercises were used and then 10 months after operation. Some of the men possibly continued the training advised, and, when possible, instituted before evacuation after operation.

Operative failures, with a few exceptions, were omissions. Incomplete procedures and neglect of drainage were the worst faults to which probably can be added the failure to introduce two-stage operations.

The worst showing is in the extended period of immediate disability (130 days). It shows that recoveries were more protracted and less complete than they should have been. On the other hand the permanent disability ratings, an average of 16 per cent for the series which errs on the higher side, is proof of what was accomplished.

In order that the full significance of the ultimate disability ratings and the reasons therefor are appreciated three facts are emphasized: (1) An average disability of 16 per cent was obtained in 66 men; 63 per cent of them had been subjected to major thoracotomies, some with multiple rib resections, some with resections of part or most of a lobe and in some the diaphragm was used to secure parietal closure. (2) An understanding of what this means will be easy when it is known that the average disability rating of soldiers treated in the camps in the United States for post-pneumonic empyema was reported as being approximately 50 per cent. (3) The results obtained in treating the wounded can not be attributed to unusual operative skill or to especially effective after-care, but only to the employment of methods which had been determined by intrathoracic physiologic actions and reactions.

CONCLUSIONS

The principal secondary influences that determine recoverability from chest wounds are (*a*) the condition of men when wounded, (*b*) the promptness with which relief is provided, and (*c*) its effectiveness.

Fighting men can not always be well fed and watered or kept free from fatigue and the mental depression inevitable with reverses, all of which have untoward effects upon the wounded. Our Army experienced no continued and but few localized defeats, so this factor was eliminated. Cheerfulness was an almost unbroken rule.

Promptness depends upon getting the wounded back to hospitals and in keeping hospitals as close to zones of conflict as relative safety permits. Transportation is essential to both. Transportation handicaps, however avoidable or unavoidable, caused great hardships to the wounded and materially increased mortality and morbidity rates.

Early wound dressing was very good. Sucking wounds should seldom be sutured provisionally. Firm pressures swathes to provide support and fixation would have been helpful. Morphine should be given in full doses and repeated. Prophylaxis and treatment of shock can be improved. In addition to means to get men warm and dry, provisions are needed for more general employment of intravenous remedies, particularly in advance of mobile hospitals. A satisfactory method of preserving blood, based upon the work of Weil,[49] will provide for a limited number of transfusions. In addition some hypertonic carbohydrate solution, insulin and digitalis now seem to be essential and should be used in spite of the less dangers of inducing secondary hemorrhage to combat certain death from prolonged hypotension.

The need for further preoperative care, including physical and fluoroscopic examinations, and of consecutive after-care, providing similar examinations, early and progressive activation has been established.

The efficacy of surgical procedures based upon physiological principles in providing opportunities for recovery with the least danger, delay and disability has been proved and warrants positive statements.

All chest wounds, severe enough to demand more than temporary dressings, should be treated by operations conducted under positive pressure gas analgesia.

Parietal excisions, usually with paracentesis, suffice to protect the least seriously injured and to hasten recoveries without added danger. They may likely prove a first-stage operation in the care of those so seriously wounded that any additional primary intervention except perhaps aspiration or the insertion of an intercostal drain is prohibited.

Limited thoracotomy is applicable in the treatment of the less severely wounded in whom deep repair can be effected through slight enlargements of entrance and exit wounds and from whom the bulk of hemothorax can be aspirated by large cannulæ introduced through a defect in parietal pleura.

Limited thoracotomy can be employed as a first-stage operation when deep injuries require an amount of repair that could not then be tolerated. Under such conditions, hemostasis and primary drainage would be required.

Thoracotomy of necessity, a more extensive application of limited thoracotomy, must be used when immediate deep repair is required and when there are reasons for using the wound defect in the parietes to secure exposure. If it be found that the repair required can not be effected with obtainable exposure or if the patient's condition prevents satisfactory operation, hemostasis, primary drainage and parietal closure can be secured and the complete operation postponed, to be performed through a separate incision.

Thoracotomies of election will find wider application as primary procedures, and if two-stage procedures are practicable, they will be the preferable secondary

operations. They afford sufficient exposure for a satisfactory examination of a pleural cavity, permit repair of most visceral and diaphragmatic lesions, heal well and impose little disability. Indeed, with the development of simple and effective methods of primary drainage thoracotomy of election may prove to be the safest treatment of massive pneumothorax unless the patient's condition be poor.

The value of two-stage operations, should they prove feasible, will be greater than in affording better care. A good proportion could be sent, after the primary operation, to evacuation hospitals where the final operation would be performed. Thus the mobile hospitals could be relieved for more strictly emergency service.

We have attempted to indicate our therapeutic failures so positively that similar mistakes need not be repeated. Contributory causes for failure will be mentioned for the same reasons, namely, so that repetitions may be avoided.

Success can be realized if personnel competent to give treatment and the materials essential to that treatment are so organized and disposed that the wounded may be well and promptly served. From a medical viewpoint, service to the wounded men is all important; from a military standpoint, service to the fighting men is most important. The exaggerated individualism of civil surgeons lead them to misunderstand or to fail to appreciate the responsibilities of their colleagues in the Regular Service to Army organization and administration. Similarly, the medical officers of the regular service apparently underrated the personal aspirations of doctors and nurses to provide their patients with the best care. Both sides were unprepared to fulfill their obligations and neither hesitated to hold the other responsible, justly and unjustly, for their own deficiencies. Jealousy, suspicion, distrust, and resentment prevented cooperation. The wounded man paid the bill with avoidably high mortality and disability rates.

There was a rapidly progressing improvement in all departments which showed that had the war continued solutions might have been found for even the most involved problems. Thereby was indicated a means to preparedness.

An army must be an autocratic organization, but many evils peculiar to autocracies can be minimized. This can be accomplished effectively so far as the Medical Corps of the United States Army is concerned by developing cooperation in advance. Civil surgeons can and should prepare themselves not merely to give professional services but to give them under the restrictions of military methods, the worst attribute of which is inflexibility. Similarly, the officers in the Regular Medical Corps, kept directly in contact with progress and changing requirements of surgical practice, will find more liberal interpretations of regulations, which are fixed products of past experiences and often are literally opposed to immediate necessities. National security should be enough of an incentive to produce the necessary personal adaptation and coordination of effort.

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CHAPTER XV

WOUNDS OF THE ABDOMEN

The man with an abdominal wound presents one of the serious problems which the military surgeon has to face. No other group of cases furnished anything comparable to it in testing the medical resources of an army or the technical skill of its surgeons. Although gunshot wounds of the abdomen comprise a small but indeterminate percentage of the total wounded (in the American Expeditionary Forces the relative frequency was 3.3 per cent of those admitted to hospital, no account being taken of the killed in action)[1] the severity of the lesions encountered and their complex nature call for the highest surgical judgment in diagnosis and treatment. The problem is full of interest to every surgeon and challenges his best thinking.

In the war of 1914–1918, the attitude of surgeons with reference to abdominal wounds underwent a marked change. In the Spanish-American War and the Boer War the expectant treatment was followed,[2] and few surgeons then had the courage to argue for and practice operative interference in these cases. The occasional patient on whom operations had been attempted almost invariably succumbed, chiefly because intervention had been too long delayed. This inevitably resulted from fighting over an open country with a rapidly shifting line, for properly equipped hospitals could not be placed near enough to the firing line to be of any service to the seriously wounded soldier.

During the early months of the great war, conservative management of the wounded abdomen was still generally advised and practiced. This was due to the open nature of the warfare and the impracticability of establishing well equipped surgical hospitals sufficiently near the front line. On the other hand, early in 1915, after the battle lines had become fixed, there began to be evident a movement, both among the surgeons of the Allies and German surgeons, for surgical intervention, and this effort gained rapidly in favor.

The reasons for this change in surgical attitude lay largely in the growing appreciation of the truth of three factors: First, that the man with a wound of the abdomen, nonoperated, usually dies. Gibbon [3] stated that in 19 months' active service overseas he did not see a single instance of recovery following nonintervention in penetrating or perforating abdominal wounds. Second, that the time factor is vitally important because of the frequent presence of serious hemorrhage, and, with a hollow viscus injury, especially the small intestine, the rapid development of spreading peritonitis. Third, that the intra-abdominal wounds in the war just ended were definitely more grave than in preceding wars because of the nature of the projectiles used. Machine-gun bullets and high-explosive shell fragments in particular often caused extensive lacerations of the bowel wall, sometimes completely severing it, and at other times excavating large areas. These lesions were in marked contrast to the clean-cut, punctured rifle wounds of former conflicts.

Before proceeding with a detailed study of the wounds themselves, it is important and essential that consideration be given to certain subjects which are vital in the proper care of the abdominally wounded.

SPECIAL PROVISIONS FOR THE CARE OF ABDOMINALLY WOUNDED

TRANSPORTATION AND THE TIME FACTOR

It becomes evident at once that, whether with a fixed or moving line, the abdominally wounded man must be rapidly evacuated to the hospital where surgical treatment may be applied. Transportation, therefore, becomes an exceedingly vital problem. The motor ambulance made possible much of the advance in abdominal surgery by cutting down materially the time elapsing between the receipt of the injury and operation.

Various factors, however, interfere with rapid evacuation, such as the severity of the fighting, the number of wounded men, the mobility or immobility of the line, the terrain, and the condition of the roads as to number, surface, and traffic requirements. Wallace [4] found that in a study of 1,200 cases of gunshot wounds of the abdomen most cases arrived at a casualty clearing within the first six hours. Only those evacuations accomplished within the first six hours were considered good; after that time the chances were against the patient.

Ambulances should be provided with heating facilities, such as the British used, that patients may be evacuated in cold weather, warmed and, therefore, less shocked and with better chances of recovery following operation. The writer took many a dead man from an ambulance in which the other occupants were stiff and cold, with the firm conviction that some of those lost might have been saved had the ambulance been provided with a heating appliance.

At times horse-drawn ambulances have demonstrated their usefulness when with roads absolutely blocked and motor evacuations at a standstill the horse-drawn vehicle has been able to carry patients over an open country and bring the seriously wounded where surgical aid was available. A certain number of such ambulances should always be included in a divisional organization, that such special evacuation emergencies may be successfully met.

A well-organized front line evacuation is essential to the proper surgical care of the abdominal case. This effort is difficult enough when trench warfare exists, but during an advance it requires the best in organization and heroism in order to insure the least possible delay. The most capable surgeon and the best equipped hospital are of no avail if the wounded do not reach the hospital within 12 hours.

The time factor is recognized as an all-important element. In general, the patient must be seen in the first 12 hours if a wounded hollow viscus is to be successfully treated surgically. Those operated upon within the first eight hours yield definitely better results. No other consideration compares in importance to the element of time; recovery percentages are inversely proportional to the time factor rather than to the organ involved or the number of lesions encountered.

THE NONTRANSPORTABLE HOSPITAL

Special provision had to be made far forward where abdominal cases could receive early and adequate surgical care. With a fixed line small hospitals naturally came into being, placed 6 or 8 kms. from the firing line. They were well housed, usually in wooden huts or chateaux, with completely equipped operating and radiological units and well organized wards. A surgeon of ability was placed in charge of such a unit and the staff requirements, including a small nursing quota, were limited. The French and the Belgians made this type of hospital an integral part of their organization, and as time went on each sector of the line had its advanced hospital for the transportable wounded to care for men with wounds of the abdomen especially, of the chest, and for those suffering from shock or hemorrhage.

THE MOBILE UNIT

No consideration of abdominal military surgery can be complete without taking into account the necessity for well-organized and equipped mobile units for the care of the seriously wounded, well up toward the front. When the war of movement began in the spring of 1918 a different type from the stationary nontransportable hospital had to be evolved, so organized that it could move with an advancing or retreating line and still provide satisfactory surgical care for the severely wounded. As told in Chapter V of Volume VIII of this history, the French had devised this type of advanced hospital, known as the *auto-chir*, and, likewise, a lighter form, the *groupe complémentaire*, and had made use of them on numerous occasions. The American Army adopted both these units, calling them the mobile hospital and the mobile surgical unit, respectively.[5] They were controlled by a capable surgeon with adequate assistants; the mobile hospital had trained nurses. The bed capacity of the mobile hospital was 120; upon its ultimate standardization, 20 3-ton trucks were required for its transportation.[6]

Such a hospital should be placed as far forward as is compatible with reasonable safety to patients and personnel, but no farther. It is very difficult to maintain morale and surgical efficiency when such a unit is under shell fire. Under these conditions the patients become terrified, it is exceedingly difficult to carry on any effective work, and a hasty evacuation of all patients may be imperative. Patients with abdominal wounds who had done well after operation in such a mobile hospital have been known to die following their evacuation to the rear.

It has been claimed that proper postoperative care could not be provided by the mobile unit if an offensive with an advancing line were in progress, as military necessity would compel the moving forward of the hospital and the evacuation of all postoperative cases. The organization of such a unit may include a rear echelon consisting of a certain number of officers and enlisted men who may be left behind with a portion of the tentage and supplies to complete the 8 or 10 days of postoperative care required for abdominal cases. When such patients finally are evacuated the echelon moves forward to join the major portion of the unit. Another effective way of dealing with this problem con-

sists in making use of a second mobile unit, which passes the hospital already established and establishes itself in a more advanced position, while the unit behind completes the postoperative care of the nontransportable cases.

INCIDENCE

The true incidence of gunshot wounds of the abdomen among the members of the American Expeditionary Forces is not known nor can it ever be; many men so wounded died upon the battle field from shock and from hemorrhage. However, this cause of a discrepancy in our statistical data is counterbalanced somewhat by the fact that many men, otherwise wounded than in the abdomen, also died on the battle field. Since diagnosis tags were used by medical personnel in the trenches and at battalion aid stations, and since these tags eventually became more detailed medical records, thus including men with severe abdominal wounds but who perhaps died while being evacuated to a hospital, it is reasonable to conclude that the relative incidence of wounds of the abdomen may readily be determined from the records so made. Thus, of the 147,651 men wounded by gunshot missiles, 5,631 were wounded in the abdomen (including the pelvis),[1] a relative frequency of 3.3 per cent. Considering the incidence from another viewpoint: Many of the men suffered multiple wounds, thus making the total number of wounds 170,841, and the relative frequency of wounds of the abdomen among these 3.8 per cent.[1]

MILITARY IMPORTANCE

At first thought one would say at once that from the military standpoint the soldier with an abdominal wound is much less important than the man slightly wounded. The latter may reasonably be expected to return to the firing line at an early date while the former may be months in the rear or may never return to the front. Further, the small proportion of intraabdominal lesions encountered would seem to make them of decidedly less military importance. But, as a matter of fact, the proper care of abdominally wounded men is exceedingly important from the side of the morale of the Army, for it gives its soldiers the conviction that any man badly wounded will receive the best chance for his life that surgery can give him. Humanity dictates that every combatant seriously hit by enemy fire shall have a chance to live.

NONPENETRATING WOUNDS

INVOLVING THE ABDOMINAL WALL

These include gutter wounds; perforating wounds running tangential to the peritoneum; wounds, with the missile lodged in some portion of the anterior or lateral abdominal wall or posteriorly in the retroperitoneal tissues or muscles of the back. Any type of projectile may cause such a wound.

The gutter abrasions make their own diagnosis. They call for complete débridement, with primary closure if the case can be held under the operator's observation for at least one week, during which time any symptoms of wound infection may quickly be recognized and promptly met. In times of great

activity, where a possibility exists of an early evacuation of the case, the wound, after débridement, should be left widely open and treated with Carrel-Dakin dressings, a delayed primary or a secondary suture being done at a later date. It is well to remember that some apparent gutter wounds are really penetrating wounds, the gutter in these cases growing deeper as the course of the projectile is followed. When any doubt exists, X-ray diagnostic aid must be made use of.

With a perforating wound of the abdominal wall the shorter the tract the less likely is one to encounter a visceral involvement. With a through-and-through wound the missile may change its direction, after entering the soft tissues, without any impact with bone, and travel along the abdominal wall, emerging at some distance from the point of entrance. Such a case may present great difficulties in diagnosis, for the two most important local signs of a visceral lesion—muscular rigidity and tenderness—are marked, as a result of muscle traumatism, even when no abdominal perforation has occurred. The patient's general condition, with lack of pulse elevation and gastrointestinal symptoms, is the important guide to a correct diagnosis. It is well for the surgeon to bear in mind that in visceral perforations seen very early general signs may be absent. The X-ray examination is of little aid in the differentiation. With clean-cut rifle wounds no intervention is necessary, but if definite doubt of abdominal perforation exists it is necessary to operate without delay. Wounds caused by shell or grenade fragments or machine-gun bullets should be completely dissected and the rule for or against primary closure outlined for gutter wounds should be followed.

The determination of the true nature of wounds of the parietal wall, with entrance only, is at times as difficult as that when both entrance and exit exist. The same local signs frequently are present and the differentiation from cases of peritoneal penetration must be made in a similar manner. The radiological findings, however, usually make the diagnosis for or against peritoneal penetration, and too much stress can not be placed upon the necessity for this type of examination. Dissection of the tract with removal of the foreign body is the course to be followed. The rules for suture are the same as those outlined above.

SUBCUTANEOUS RUPTURE OF VISCERA

The literature of civil surgery and of former wars has yielded many examples of this sort of abdominal lesion; that concerning the recent conflict has been equally prolific. In the Medical and Surgical History of the War of the Rebellion numerous types and variations of subcutaneous abdominal injuries are cited in great detail.[7] In war, as in civil life, injuries of this sort are caused by the kick of a horse or a mule, by blows upon the abdomen during a fight, or by falls from a height, the man landing upon the abdominal wall. In military surgery injuries of this type are caused also by shell explosions in the immediate vicinity of the soldier (the so-called "wind injuries" of the Civil War); they may be caused by flying pieces of wood or other solid objects in connection with shell bursts; they may result from crushing injuries from falling timbers or earth incident to the bursting of a projectile.

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Two modes of injury which are especially important because of diagnostic difficulties are laceration of the abdominal wall by a missile without penetration of the cavity but with sufficient explosive force to rupture a viscus within, and visceral perforations from flying bone spicules without peritoneal penetration by a projectile.

The former injury if unrecognized leads frequently to a fatal result; the latter should always be thought of in connection with rib fractures in or about the hepatic or splenic areas or with comminuted pelvic fractures where the pelvic portion of the small intestine is the most frequently injured viscus, while injury of the bladder, rectum, and colon is less common.

The organs most often ruptured are the liver, spleen, kidney, and small intestine; the mesentery is not infrequently torn. The colon, rectum, and bladder are less often injured.

The lesions encountered may be grouped under the headings injuries of hollow viscera and injuries of solid viscera. Hollow visceral lesions may include contusions of the wall, minute perforations, extensive lacerations or even complete division in the case of the bowel or its mesentery. Solid visceral lesions comprise subcapsular rupture of solid organs, especially the liver, with usually a small hematoma beneath the capsule, slight tears, and extensive lacerations.

The diagnosis of subperitoneal rupture of any viscus or of the mesentery must be made by a consideration of the site and mode of injury, the presence of more or less anemia from hemorrhage, especially with solid visceral and mesenteric lesions, and, where a hollow viscus has been opened, the usual signs of peritoneal irritation with subsequent symptoms of a rapidly advancing peritonitis. Patients with serious injuries frequently come to the hospital in considerable shock, particularly when the degree of hemorrhage is severe or the small intestine or mesentery has been seriously injured.

Rupture of a hollow viscus calls for immediate intervention; the principles of treatment outlined under penetrating abdominal wounds should be followed. A torn mesentery with signs of hemorrhage requires immediate operation; resection is usually necessary.

With a suspected rupture of a solid viscus but without alarming symptoms or hemorrhage, an expectant attitude should be adopted. Most of these patients recover unoperated. If the hemorrhage has been severe in such a case the best working rule is to operate if the patient is seen very early, but to watch and observe for a few hours if the patient is seen six or eight hours after injury. If then the anemia is not apparently progressive one should not operate, for the hemorrhage has to all intents ceased and laparotomy will cause a renewal of the hemorrhage with a probable fatal result. If there are signs of progressive bleeding the abdomen must be opened at once.

Control of hemorrhage from a ruptured liver may be accomplished by packing or by mattress suture inserted with a large needle, blunt end first. Suture near the diaphragm or far back on the inferior surface of the liver is difficult and frequently impossible. Packing with sterile gauze should be resorted to when suture can not be effectively carried out.

In general a rupture of the spleen should be treated by splenectomy. The objection raised that convalescence is hampered by the impairment of the patient's blood forming mechanism is practically unimportant.

In all cases in which hemorrhage has been a serious symptom transfusion should be carried out as soon as possible after the bleeding has been controlled. The ease with which this procedure may be carried out, either with the aid of paraffin-coated tubes or by the citrate method, the prompt and striking improvement in the wounded following transfusion for hemorrhage, and the abundance of robust individuals among the slightly wounded who may serve as donors, should serve to make this operation a routine procedure early in the treatment of hemorrhage.

PENETRATING AND PERFORATING WOUNDS

GENERAL CONSIDERATIONS

The general principles of military surgery of penetrating wounds of the abdomen differ but little from those employed in civil life. However, many factors obtain to make the problems of abdominal surgery complex and difficult, and each case must be studied in the light of accumulated experience in the war zone.

Before the types of injuries involving special organs are discussed certain general principles influencing the diagnosis and management of abdominal wounds must be considered. As the patient is admitted the questions which arise are: (1) What is the man's general condition with respect to shock? (2) What is the diagnosis? (3) Is operation indicated?

Several factors contribute to bring the soldier with an abdominal wound to the hospital in a condition of shock. These are lack of sleep and food, exposure to cold and wet, difficult evacuation to the hospital, traumatism of abdominal and visceral walls, hemorrhage, pain, and infection, the latter being especially important in those arriving late. Hemorrhage, save in the late cases, is the great factor in the production of shock, and the degree of shock is usually proportionate to the severity of the hemorrhage; undoubtedly many combatants die on the battle field from rapidly fatal intraabdominal hemorrhage. The abdominal cases reaching the hospital show most extensive hemorrhage when the mesenteric or pelvic vessels or when the liver, spleen, or kidney have been injured.

Hemorrhage may also occur from the abdominal wall, the omentum, and from the retroperitoneal tissues. In the latter case the loss of blood may occasionally be alarming and the diagnosis very difficult. Since hemorrhage is one of the principal causes of fatal issue in the abdominally wounded, it is therefore an important argument for the earliest possible intervention. Inactive hemorrhage from a solid viscus does not constitute an indication for operation.

Pain is usually a distinct symptom. The pain in the wounded parts, increased by difficulties in evacuation, and the pain caused by an advancing peritonitis both contribute to the shocked state of the wounded. Moreover, the degree of shock found is in approximate ratio to the time elapsing before the administration of morphine.

Cases with infection of the retroperitoneal tissues may show rather pronounced shock. Infection due to the presence of anaerobic microorganisms in badly lacerated muscles of the abdominal wall may be an important factor. The shock which accompanies an advancing peritonitis is readily recognized.

A hurried examination having been made to assure the surgeon that no progressive hemorrhage is present and that no splint readjustments are necessary, immediate treatment directed toward the relief of shock must be instituted. The preoperative ward of a hospital for seriously wounded should be organized to deal particularly with this condition. Since the subject of shock and its treatment is covered in detail in Chapter VII of this volume, no further reference is made to it here.

Bound up with the question of an accurate diagnosis are the questions of abdominal penetration and visceral injury. A tangential abdominal wound, especially if the tract is a short one, frequently gives no peritoneal penetration. With such wounds, where peritoneal irritation is lacking, the probability of abdominal entry is small. As demonstrated by Wallace,[8] a wound above the pyloric level with entrance and exit to the right of the median line seldom results in visceral injury though the peritoneum may have been entered. Other through-and-through wounds mean certainly that the peritoneum has been penetrated but occasionally without visceral injury.

With only a wound of entrance, diagnosis becomes more difficult, and under these circumstances the X ray may give the greatest aid to the surgeon. Accurate information quickly obtained by means of a roentgenological examination is often the most important guide to the character of the wound with reference to visceral injury and to the exact situation of the missile.

SYMPTOMS OF VISCERAL INJURY

The general symptoms are those of shock, hemorrhage, pulse acceleration, and vomiting; the local ones, abdominal pain, tenderness, rigidity, and distension. The symptoms of shock are well known and its causes in abdominal injuries have been already enumerated. There may be no symptoms of shock even in the presence of serious visceral injury.

Though hemorrhage may produce little in the way of physical signs, the cardinal symptoms are a rapid, soft pulse, a low blood pressure, and obvious anemia. Patients with hemorrhage may exhibit excessive thirst and frequently show signs of air hunger. With any amount of bleeding intraabdominal fluid may be detected in the flanks, and local peritoneal signs may be moderately marked. The face is blanched and listless when the degree of hemorrhage has been considerable; it is anxious when infection in the peritoneum is progressive.

Whether there is hemorrhage or not, pulse elevation is the rule. With a peritonitis in progress the pulse rate steadily rises, and this sign is one of the valuable guides in demonstrating hollow visceral lesions. It is especially important in excluding a parietal wound with considerable muscle injury where local signs of peritonitis may be closely simulated.

Vomiting is usually present with a hollow viscus penetration and becomes more marked as peritonitis becomes more severe. Gastric wounds give earlier vomiting, with a vomitus frequently containing blood. On the other hand

wounds of the stomach sometimes occur with an entire absence of vomiting, so that this symptom can not be termed characteristic of gastric injury.

There is a great variation in the degree of abdominal pain, and the surgeon can not pass judgment upon the severity of the visceral lesion from the amount of pain the patient suffers. The location of the pain usually gives little aid in the attempt to localize the viscus injured. The most important feature of the pain from a diagnostic standpoint is its inception simultaneously with the receipt of the wound. The soldier abdominally wounded may have received a considerably dosage of morphine prior to admission to hospital, and if this has been promptly given his complaint of pain may be absent, particularly if he is seen early.

The local tenderness is the most pathognomonic sign of a ruptured hollow viscus and is the most constant physical symptom of peritonitis. It is always present and is localized over the region involved. It may be masked somewhat by morphine but it never disappears completely. Tenderness is also present with parietal wounds and contusions, but the other signs of visceral penetration are lacking.

Muscular rigidity is a very important sign of visceral injury, but it is less constantly present than tenderness. Charles [9] has seen cases of multiple perforation with an entire absence of muscular rigidity and again has encountered boardlike rigidity in severe wounds of the abdominal wall. Wallace [8] and many others have enumerated certain injuries which may be accompanied by marked rigidity without injury of an abdominal viscus. The more important are chest wounds with no abdominal lesion, wounds of the abdominal wall, and hemorrhage into the retroperitoneal tissues. The rigidity of an advancing peritonitis is generally progressive and increasing in intensity, while rigidity from introabdominal hemorrhage is less marked, and usually diminishes gradually if the hemorrhage has ceased. Muscular rigidity as well as local tenderness may be all important symptoms in diagnosing a visceral perforation when the wound of entry is in some remote region and the possibility of an abdominal lesion seems very unlikely.

Abdominal distension is not an early or important symptom of visceral penetration. It becomes more pronounced as peritonitis develops, but it is then of little value in diagnosis.

INDICATIONS FOR OPERATION

Certain groups of cases come to the hospital in which operation is contraindicated and these may well be considered here.

Moribund patients should be made as comfortable as possible with morphine. A so-called moribund ward is practicable and fills a good purpose. The patients in it must not be left surgically unattended but should be followed through to the end.

Cases with general peritonitis from a hollow viscus injury 24 or more hours old are generally hopeless subjects for radical treatment: Nearly 100 per cent mortality occurred among such of our cases following operative intervention.[1] The expectant plan should invariably be followed. Morphine in liberal doses, Fowler's position, heat, rest, alkaline fluids, sugar solution by rectum,

and saline solution beneath the skin are the lines of treatment to be followed. These cases must be carefully separated from the moribund class. Unless they are kept under constant supervision the rare individual whose peritoneal defense mechanism may bring him into the operable class may lose his only chance for life, because the psychological moment for operation is passed unnoticed.

Except for the individuals in whom shock is due to progressive hemorrhage the badly shocked should be kept in the preoperative ward under the eye of the ward surgeon, but the final decision as to operability or nonoperability must rest with the operating surgeon. When there is no amelioration of the symptoms of shock, operation should not be performed. As a working rule, the patient who shows no tendency to reaction within two or three hours never reacts.

Cases with through-and-through wounds of solid viscera without progressive hemorrhage do well without surgical intervention: the chances of recovery are better when no operation is performed. The presence of hemorrhage in these patients is usually differentiated from an advancing peritonitis by the pulse rate of 80 or 90. Such a patient should not be interfered with. Intervention frequently results in a renewal of the bleeding when the abdomen is opened and disaster may follow. Fluids by rectum or by hypodermoclysis with moderate morphine dosage are the indications. If the loss of blood has been considerable, transfusion may be resorted to when a fair degree of certainty exists that hemorrhage has ceased.

Short tangential wounds with unimportant abdominal symptoms, seen 8 to 10 hours after injury, are best left unoperated, but no such patient should be sent from the preoperative ward to one of the postoperative wards. During the height of an offensive military operation such an individual may easily escape the eye of the ward surgeon and a case in which operation may have become definitely indicated may be overlooked.

The basic indications for immediate operation are symptoms pointing to progressive intraabdominal hemorrhage or hollow visceral penetration. Walters [10] and other surgeons speak of the obvious necessity for operation in cases with visceral or omental protrusion; in cases with escape of gas or feces through the wound; and in cases with subcutaneous emphysema from the escape of intestinal gas, usually from the large bowel, into the tissues adjacent to the wound. Emphysema of such origin appears shortly after the receipt of the injury in contradistinction to the emphysema of gas gangrene.

In a time of great stress the problem of the seriously wounded may be a difficult one to handle. Practically it must be managed by first operating upon the best operative risks. When the stream of badly wounded becomes tremendous severe cases with wounds other than abdominal and with better hope of recovery must have the chance of life which operation gives. A frequent revision of the cases in the preoperative ward must be made that the surgeon may assure himself that no soldier with a fair chance of recovery with operation is passed by.

A good working principle is to operate if doubt of a hollow visceral lesion exists, for the mortality of such operation is exceedingly low when no visceral

penetration is found. In our evacuation hospitals the mortality for this type of operation was 6.5 per cent.[11] Exploration of the abdomen with negative visceral findings is attended, therefore, with little risk, compared to the uncertain possibilities of a serious advancing peritonitis if the man is left unoperated.

OPERATIVE TECHNIQUE

Since no type of war wound presents such a complex problem as the penetrating wound of the abdomen, the details of surgical technique must be studied with the greatest care.

There is little doubt that nitrous oxide-oxygen is the least toxic and the best borne of all the narcotizing agents, but, unfortunately, it does not give the complete muscular relaxation which is essential to efficient abdominal surgery. Its administration requires a skilled anesthetist and a bulky apparatus.

Ether is the agent universally employed and is by all odds the anesthetic of choice for abdominal cases. The ordinary open method of administration gives reasonably satisfactory results; the equipment required is the minimum. Marshall,[12] with an extensive experience, found fewer complications when a warmed ether vapor was used, but in the American Army this method was not given a trial.

The shorter the period of anesthesia the less the degree of toxemia that will be produced and the better the prognosis for the patient.

Two general rules may be followed to aid the surgeon in his choice of an incision: (1) Plan the incision to meet the visceral injury suspected; (2) avoid, if possible, the projectile wound site, and so diminish the liability to wound infection. Always make the operative wound sufficiently ample to insure an unhampered exploration. A wound of 8 or 10 inches usually suffices. Some advise the paramedian incision as the one for general use, while others favor an opening in the median line either above or below the unbilicus, depending upon the organ probably injured. The latter is the incision of choice in most cases. For the upper abdomen some operators prefer a transverse incision or an oblique one parallel to the costal margin. This gives excellent access to wounds of the spleen, liver, kidney, or upper colon. The greatest objection to this type of incision is the difficulty in making a neat, rapid, and satisfactory closure. With a lesion below the umbilicus, and a wound in the flank, a transverse or oblique incision should be made. Such an incision affords good access to the retroperitoneal tissues and wounds of the posterior aspect of the large bowel. Transverse incisions in connection with abdominothoracic injuries are considered below under such lesions.

The general principle of wound disinfection by careful dissection must be as carefully observed in abdominal surgery as in wounds of the extremities. Careful excision of all soiled tissues must always be carried out if the patient's condition permits. At times this is best done before the abdomen is opened, and the instruments used should then be discarded. Sutures may be placed if the patient may be held for 8 or 10 days, but it is safer not to close the skin. It may, however, be wiser in very serious cases to defer the abdominal wall dissection until the suture of the operative wound has been completed. Fail-

ure to carry out an efficient débridement will result in an infected abdominal wall, with the possibility of serious consequences.

Speed is important, but no false moves should be made. It must be remembered that an operation of more than one hour's duration usually means a shocked patient with little chance for recovery. Try to determine what organs may be excluded from the possibility of injury, but err on the side of thoroughness and keep the surgical traumatism to a minimum. Protect the skin adjacent to the wound with towels and skin clips to avoid contact of the cutaneous surface with abdominal contents. Do as little as possible, at the same time making the operation a thorough one.

If hemorrhage has been progressive or if upon opening the peritoneum there is more blood than was anticipated, seek at once for the source of hemorrhage and check it by clamp, packing, or suture. Considerable hemorrhage from the mesentery means inevitable resection.

Throughout the operation make the traction upon the abdominal wall as light as is compatible with proper manipulation of viscera. The detailed treatment to be applied in wounds of the various organs may be found below, where wounds of these viscera are discussed.

Closure should be done carefully in layers except in cases doing badly on the table, when through-and-through sutures may be employed. If the wound by the missile has crossed the line of operative incision it is better to leave the skin without sutures or but partially closed; and the same precaution against infection of the abdominal wall should be observed if a period of stress prevails and the work is necessarily somewhat more hurried.

No drainage should be employed in sutures of the small intestines, unless a very active peritonitis has developed. No drainage for stomach cases is necessary. On the other hand, drains of rubber dam (never gauze except to check hemorrhage) should always be used in wounds of the colon and rectum, especially those complicated by retroperitoneal injury. Gauze drainage for liver or spleen should be employed solely for hemostatic purposes. Drains are used to provide an outlet for leakage from the large bowel or to check hemorrhage, but should never be thought of as effectively draining the general peritoneal cavity.

POSTOPERATIVE TREATMENT

Practically every one of these patients has suffered a loss of body fluids, and the administration of fluid is the chief indication. For wounds of the solid viscera, stomach, and small intestines a Murphy drip of 5 per cent sodium bicarbonate solution, with or without 5 per cent glucose, is the method of choice; or similar enemas at four or six hour intervals may be substituted. For wounds of the colon and rectum, hypodermoclysis with saline solution meets the indications. Saline infusion may be used in any case where considerable hemorrhage has occurred, but only as a temporary measure to tide over the man for a few hours until blood may be obtained. Transfusion in this latter group is frequently essential to recovery, and it may be necessary to repeat it. Blood grouping should always be done before transfusion, as it takes but a moment when Vincent's macroscopic test is used. Group IV

donors (Moss' classification) may be employed for a recipient of any of the four groups. Citrated Group IV blood may be collected at a distance and transported to the hospital in sterile bottles, and such blood may be kept for upward of 24 hours without fear of clotting. If there is no vomiting, water or very dilute alkalies may be given by mouth, but no fluid food should be taken for the first 24 hours. Restoration of the physiological activity of the bowel probably requires a still longer interval.

Pain is a constant postoperative symptom and morphine is a very important therapeutic agent for its relief. It should be given freely during the first 24 hours, moderately during the second, and sparingly or not at all during the third 24-hour period. If the patient is doing badly such a rule can not be adhered to and morphine should be given freely to the end.

Distension of the abdomen is a variable symptom, but is generally fairly marked and contributes much to the patient's discomfort. It is best treated by colonic irrigation, pituitrin, and local heat when the latter may be applied without discomfort to the patient. Fowler's position is particularly valuable in wounds of the lower abdomen, since it helps to localize the inflammatory process. It also helps to relieve the distension, especially when a rectal tube is made use of from time to time. The position may be maintained fairly continuously for the first 48 hours or 72 hours.

Vomiting is usually present and may become a distressing symptom. It is caused by the postoperative ether toxemia, the peritoneal traumatism incident to the wound and the operation, to an advancing peritonitis, or to a dilated stomach. If withholding of fluids by mouth for a few hours does not result in an early cessation of vomiting, gastric lavage with warm water, with or without sodium bicarbonate, repeated at two or four hour intervals, is the most effective means of treatment. In all the conditions named, except the advancing peritonitis, lavage usually gives effective relief.

The length of stay in the hospital in which operation has been performed and definitive treatment given should be from 7 to 10 days, or longer if military necessity will permit it. The period named brings the average patient far enough along in his wound healing and general convalescence to permit a safe evacuation to the rear. A certain small number of evacuated cases may develop postoperative complications, but military exigencies will usually allow the really bad cases to be retained forward for a longer period than the time used. Above all, careful nursing and continuous care on the part of the surgeon must be available, or many patients will suffer and a certain number succumb who otherwise might be saved. The dressing must be done by the most experienced hands available, the operator or his assistant doing this work whenever it is physically possible. If a ward surgeon dresses the wounds the surgeon himself must supervise his work and personally direct the patient's convalescence.

POSTOPERATIVE COMPLICATIONS

The more frequent and, therefore, important complications are infection and the development of fecal and urinary fistulæ; secondary hemorrhage, nephritis, and pulmonary complications are less often seen.

Infection is encountered in the form of local wound infection, as a localized peritoneal abscess, or as general sepsis. The wound healing is good or bad in direct proportion to the amount of infection present in the abdominal wall. The surgeon's first effort, therfore, in combating wound infection is the prevention of it by painstaking surgery at the time of operation. Careful débridement of the abdominal wall and proper placing of the abdominal incision with respect to the wound, combined with the nonsuture of skin and subcutaneous tissues in doubtful cases, are the most important details to be observed. The surgeon must also carry out only partial skin closure in the presence of an active purulent peritonitis, as the parietal wall will necessarily be more or less contaminated. Very disastrous gas and streptococcus infection of the abdominal wall may develop, usually early in the postoperative course, and such a condition calls for wide incision, combined, where possible, with Carrel-Dakin treatment. Evisceration of considerable intestinal contents may occur with an infected abdominal wound, and such cases usually do badly. Immediate replacement of viscera must be accomplished with rapid resuture of the peritoneal muscular, and fascial layers.

Localized peritoneal abscess is more often a later complication, occurring from a few days to two or three weeks after operation. It may complicate a fecal fistula. It is the most favorable outcome to be looked for in a case of diffuse peritonitis. Considerable difficulty in making a proper diagnosis of the location of the purulent collection may be encountered. It may be placed in practically any portion of the peritoneal cavity and may point in the buttocks, perineum, or flanks. Cases of infection following local leakage into the retroperitoneal tissues are the most difficult ones to diagnose and treat successfully. The indication in all these cases is drainage by the simplest possible procedure.

General sepsis is relatively infrequent. The fatal cases of peritonitis usually die within a few days before sepsis has become general. It may occur in connection with retroperitoneal infection or with badly infected operative or projectile wounds. No effective treatment has been found to combat general sepsis successfully.

Fecal fistula is a frequent complication of wounds of the small and large intestine, being encountered most often after suture or resection of the latter. It also follows operation for inaccessible rectal injuries. It may occur at any time in the postoperative course of the abdominal wound, and the fecal discharge usually appears in either the operative wound or along the original wound tract where inaccessibility has made a careful dissection impossible. Makins [13] cautions us to bear in mind that a bruised intestinal wall without complete entry of the lumen may at times break down with the formation of a fecal fistula. Such instances have been verified by the findings of a previous exploratory operation. Frequently a fecal fistula will close spontaneously, particularly one complicating operation. In a small proportion of cases, however, suture or resection may be required to relieve the condition. Every precaution must be taken in such an operation to isolate the general cavity from the operative field; and adequate drainage, preferably with rubber dam, should be provided. Such a type of operation is usually done in the base hospital when it has become evident that the fistula will not close spontaneously.

Secondary hemorrhage is rare as a sequel to abdominal injuries. It may occur from septic erosion of a large vessel or from a reopening of a partially healed wound of a solid viscus. The treatment is the same as for primary hemorrhage.

Any of the inflammatory processes of the lung or pleura may complicate the postoperative course of an abdominal lesion; they are, however, comparatively infrequent. The most striking pulmonary complications encountered by the writer were four cases of pulmonary embolism (diagnosis being made by symptoms, since no autopsy could be performed) which were fatal in from one-half to two hours after the intravenous injection of gum solution. The further use of this agent was discontinued by the writer and his associates.

Nephritic complications are comparatively infrequent. The indications for treatment are the same as in civil surgery.

TREATMENT OF VISCERAL INJURIES

In a certain proportion of cases the peritoneal cavity is opened without any injury of the viscera. Practically this group may be considered in connection with nonpenetrating wounds of the abdominal wall. The possibility of an infection of the peritoneum from the retained projectile, or from foreign material carried into the peritoneal cavity, makes them definitely more serious than the nonpenetrating wounds. The missile, however, usually becomes encysted, when it may give no symptoms whatever. In rare instances a localized peritoneal abscess may result.

Cases with short tangential wounds, and the occasional cases in which after 8 or 12 hours no alarming abdominal symptoms have developed and in which the patient's general condition is excellent, are particularly the ones in which the question for or against operation may arise.

When any doubt of the wisdom of intervening exists it is better to operate. As stated above, it is far better to open every abdomen when there is question as to visceral injury than to abstain, for the mortality after operation where no visceral lesion is found is very small and the hazard is a tremendous one if a true perforation of a hollow organ is left without operation. Further, operation always furnished an opportunity to search for and often to remove the foreign body itself.

WOUNDS OF THE STOMACH

Stomach wounds comprise about 7 per cent of all abdominal injuries coming to the hospital for treatment. Two-thirds of all gastric lesions show no other accompanying visceral injury discoverable at operation. Wounds of other organs most often encountered are those of the small gut, liver, colon, kidney, and spleen, in the order of their frequency.[1]

The wounds are usually two in number and are most often situated on the anterior and posterior walls. If the anterior opening is small and the organ was not distended at the time of injury there may be no protrusion of mucous membrane and no escape of gastric contents. Leakage may, however, occur into the lesser sac when none is present anteriorly. If but a single wound is present it is usually of the anterior wall. Under the conditions, great care must be exercised in excluding a posterior wall perforation, for in comparison with the

injury of the anterior aspect that of the posterior may be much more difficult to detect. Lesions of the borders and orifices are comparatively infrequent. Considerable damage to the gastric wall is more often seen with wounds of the lesser curvature and those parallel to the walls of the stomach. The more ragged and larger wounds are usually caused by shell and hand-grenade fragments and machine-gun bullets fired at close range.

There are local signs of peritoneal irritation, but these are definitely less marked than with injuries of the small intestine. Only moderate shock is present in most of the cases; where a severe hemorrhage has occurred the degree of shock is profound. Exceptionally, there is no gastric leakage into the peritoneal cavity. The cardinal symptom is early and persistent vomiting. Rarely, however, vomiting may be absent. Escape of gastric contents or gas may take place from the abdominal wound.

Very rarely recovery has been reported without intervention. The safe rule to follow is operation in practically every case. The best incision is the median or paramedian. The perforation of the anterior wall of the stomach is readily recognized. The opening in the posterior wall is best sought for through the gastrocolic omentum just below the stomach. Pauchet's approach, recommended by Eastman,[14] is made through an opening in the mesocolon, the line of dissection passing just above the transverse colon. This frequently gives good access, but it is not recommended for general use, as repair work is more difficult when this technique is used. A ragged wound should be trimmed off rapidly before suture. The greatest difficulty in accomplishing a good closure of the stomach wall will be found with wounds involving the lesser curvature and those high up near the cardiac orifice. Gastroenterostomy should be avoided if possible, for a higher mortality results in the cases in which it is performed. Drainage in gastric cases should be employed only where a fairly well developed peritonitis is present or if suture of the stomach wound is difficult or impossible. The most important precaution to be observed in the postoperative care of these cases is careful feeding. Only water should be allowed by mouth during the first 24 hours and liquid diet for the following three days.

The seriousness of gastric lesions is in no wise comparable to the grave conditions caused by wounds of the small intestine. A favorable outcome may be possible even if the case is seen a considerable time after receipt of the injury, as peritonitis advances comparatively slowly. Numerous cases have recovered where operation has been performed from 24 to 36 hours after the receipt of the wound.

The mortality of all gastric wounds is approximately 55 per cent.[1] Uncomplicated wounds of the stomach give a mortality varying from 25 to 50 per cent.

WOUNDS OF THE SMALL INTESTINE

The proportion of total small intestinal wounds, complicated and uncomplicated, to all abdominal lesions is approximately 22 per cent.[1]

Wounds of the colon are much more frequently encountered than those of any other complicating visceral lesion. The injuries next in order of frequency are those of the stomach and bladder, while wounds of the liver, kidney, rectum, and spleen are still less often encountered.

Duodenal injuries are fairly infrequent, comprising approximately 6 per cent of all small gut wounds.[1] Injuries to the jejunum comprise about 23 per cent; to the ileum approximately 71 per cent.[1] Multiple lesions are almost universally encountered, at times reaching the number of 15 or 20, but the average number to be expected is from 4 to 6. The wound may be small or large, depending upon the character of the missile, the velocity at which it is traveling, and the angle of entry into the gut. When the projectile strikes the intestine vertically two perforations are almost invariably found. As a rule there is a certain protrusion of the mucous membrane, but if the wound is a small one there may be no pouting and such cases may show no leakage. The more nearly parallel the wound is to the long axis of the gut the more the damage to the visceral wall and the larger and more ragged is the wound itself. Extensive laceration of the intestinal wall and even complete division of the gut are not so very unusual; in such cases a considerable tearing of the mesentery is frequently found. The mesenteric lesions are especially important from the standpoint of hemorrhage and because of the necessity for resection with its added shock and operative hazard.

It is generally best to begin the exploration of the gut at the ileocecal valve, but if the wound is high up the duodenojejunal junction may be first examined. Work rapidly upward, if beginning at the ileocecal valve, or downward, if beginning at the duodenojejunal angle, being careful to replace within the abdomen every 8 or 10 inches of segment after its examination. In this way the entire ileum and jejunum with their mesentery are carefully examined for perforations. When a wound of the intestine is encountered clamp the opening tightly, protect it with a pad, and hold it outside the abdomen, and as each lesion is discovered treat it in the same way. It is a good general rule to refrain from repairing any perforation until the entire length has been examined. The writer has seen a small gut suture, requiring 15 minutes, performed upon a segment of small intestine that later had to be resected because of mesenteric injury. Exception to this rule may be taken when normal bowel and mesentery are present several inches to each side of the lesion or where a large number of perforations with their pad coverings would form a serious obstacle to efficient technique.

Careful search for complicating wounds of the stomach should then be instituted and the lesions appropriately treated. Other visceral injuries should be sought for and the colon should as a rule be the last one explored, as lesions here may necessitate performing a colostomy. If, during the course of an operation, a wound of the colon is encountered, it is wiser to treat it immediately if suture only is required.

The vast majority of small intestinal wounds are satisfactorily closed by a single purse-string suture of silk or chromic gut. Suture should always be practised if possible, as resection is attended with far greater hazard. With numerous small lesions close together, suture is preferable; if gut damage has been considerable, resection may prove to be the better procedure. The best rule is to resect only when it is impracticable to suture. A double row of sutures should always be employed when resection is done.

The postoperative care of cases with small gut injury has been outlined above under the general discussion of penetrating abdominal wounds.

The frequency of wounds of the small intestine and the high mortality attending operation for their relief make these injuries the big problem in abdominal military surgery. The mortality rate in cases of wounds of the small intestine in the American Expeditionary Forces, including the operated and unoperated, was as follows:[1] Duodenum, 80; jejunun, 78.8; ileum, 73; small intestines (not specified), 70.9. Resection gives regularly a mortality 50 per cent higher than does suture.

WOUNDS OF THE COLON

Wounds of the colon represent about 22 per cent of all intra-abdominal visceral injuries.[1]

Perforating wounds of the colon are much less often multiple than those of the small gut because of the lack of numerous intestinal coils. The multiple lesions that occur usually involve the pelvic colon. Some of the smaller perforations may be due to minute bone spicules penetrating the bowel wall, and this type of lesion is much more difficult to recognize than an injury primarily due to a missile. Some of the wounds are large and ragged and a complete division of the bowel may be found, but less frequently than in wounds of the small intestine.

Retroperitoneal perforation with its consequent fecal leakage and cellulitis constitutes one of the difficult problems to be dealt with. The posterior perforation may be a minute one which is difficult to recognize. Injuries of the portions of the gut which are without a mesentery, the ascending and descending colons, are particularly liable to be accompanied by a serious retroperitoneal infection. Retroperitoneal injury of the transverse colon may only be detected when the lesser sac is explored.

The symptoms and diagnosis of wounds of the colon have been considered above in the discussion of abdominal wounds under the heading of "Diagnosis." The special factors which make diagnosis difficult are the liability to retroperitoneal infection and the inaccessibility of the splenic and hepatic flexures, particularly the former. A grave acute sepsis may rapidly develop in connection with retroperitoneal cellulitis. Further, the type of peritonitis which the surgeon encounters in connection with perforations of the colon is very likely to produce more aggravated local and general symptoms than that associated with the involvement of the small intestine.

No one incision will satisfy all requirements with wounds of the colon. A median or paramedian incision is best used when a lesion of the transverse or pelvic colon is to be dealt with. The best incision for wounds of the cecum or of the ascending and descending colon is a transverse one in the flank, for this allows an easy access to the posterior portion of the bowel and a better chance of discovering a posterior perforation. The incision of choice for either of the colonic flexures is a subcostal incision on either side, prolonged vertically downward if additional space is required. This incision is particularly valuable on the left side because of the posterior position and inaccessibility of the splenic angle. The general principles to be followed are: Suture whenever possible

to secure a satisfactory closure, and always employ a double row of sutures. Avoid resection; colostomy is to be preferred. If a colostomy is performed a resection done at a later date sometimes gives a satisfactory result. Colostomy is to be advised with large ragged openings, particularly those occurring in the cecum, descending colon, and sigmoid. Drainage is a most important factor with wounds of the large bowel. Always drain when any doubt of the integrity of the suture line exists and in every case of proved or questionable retroperitoneal injury.

There is a slightly lower mortality record with wounds of the large intestine than with those of the small bowel, the figure for the former being 59.6 per cent.[1] The cases that do badly die from retroperitoneal sepsis, which may be most acute, or from a peritonitis secondary to fecal leakage, preceding or subsequent to operation. The wounds that are sutured do better than those in which an artificial anus is employed; the latter group gives the high mortality rate of 70 per cent.[1]

WOUNDS OF THE RECTUM

Injuries of the rectum are comparatively infrequent, constituting 2.4 per cent of the lesions of abdominal viscera.[1] Complication by other injuries is infrequent. Associated lesions which may be encountered are those of the bladder and pelvic colon, or, less frequently, injuries of the small bowel.

The lesions vary in size from small perforations caused by a minute projectile or a fragment of bone to extensive lacerations. Wounds of the rectum often show a wound of entrance in the buttock or upper portion of the thigh or in the perineum. If the wound is an extraperitoneal one, fecal leakage posteriorly may occur, with the rapid development of a grave cellulitis.

Intraperitoneal injury of the rectum gives rise to a rapidly developing acute peritonitis which is still more aggravated if complicating lesions are present. A wound of entry through the buttock or perineum in a patient exhibiting symptoms of peritonitis in the lower portion of the abdomen should always make the surgeon suspicious of a rectal injury. Local tenderness in the posterior rectal wall made out by the examining finger in the rectum and associated with evidences of infection in the perineum always suggests an extraperitoneal rectal wound, especially when associated with general symptoms of a septic type.

The extraperitoneal injuries are best treated by careful débridement of the buttock or perineal wound, the dissection being carried upward and into the rectum. It may be necessary to open widely the lower segment of the bowl in order that complete dissection of the tract may be accomplished and that adequate drainage may be most effectively placed in the retroperitoneal tissues. Extensive lacerations of the lower segment may require a colostomy. Intraperitoneal injuries are treated by a median laparotomy with suture of the opening wherever it is possible to accomplish it. Drainage through the lower angle of the operative wound should always be practiced, rubber dam being the best material for the purpose. If a suture can not be made, owing to the depth of the rectal wound in the pelvis, a colostomy should be performed.

The mortality with wounds of the rectum is 45.19 per cent.[1] Usually death is due to a rapidly advancing sepsis in the retroperitoneal tissues or to a severe spreading peritonitis.

WOUNDS OF THE LIVER

Wounds of the liver comprise 13.3 per cent of all abdominal injuries.[1] Approximately three-quarters of all liver lesions are uncomplicated ones. Associated wounds to be considered are, in the order of frequency, wounds of the colon, stomach, and kidney; injuries of other organs are much less often found.

Clean-cut liver wounds are very unusual. There may be any type of lesion from a small perforation to a slit or a large ragged excavation, and in some cases a loss of liver substance is encountered. Whatever the type of projectile, a large wound of exit is to be expected, and lacerations in all wounds is the rule.

Hemorrhage is always present, varying from a slight oozing to a severe and rapidly fatal hemorrhage. More often the bleeding tends to subside spontaneously. Peritoneal symptoms are to be expected from the presence of blood in the peritoneal cavity. A dullness in the flanks, particularly on the right side, may be made out if the amount of bleeding has been considerable. A case seen two or three days after the injury frequently shows a slight degree of jaundice; late jaundice usually means sepsis. Where the loss of blood has been considerable the patient exhibits a marked degree of shock.

The diagnosis of liver injury is made from the position of the wound and the symptoms of intraabdominal hemorrhage. The early appearance of jaundice should make one suspicious of liver injury.

As a general rule the expectant treatment should be followed. Operative intervention should be made when other visceral lesions are suspected, where the hemorrhage is serious and progressive, or where the foreign body retained is a very large one. The incision best suited for the management of liver wounds is a right subcostal one, though a median or paramedian approach may give adequate exposure. When the abdomen is entered, if a small wound is found without active hemorrhage, it should be left alone. A larger wound from which the bleeding has ceased should be packed or sutured, preferably the latter, for secondary hemorrhage from such a wound is not unlikely. In placing sutures use a large round needle, blunt end first, the suture being of a mattress type. This form of suture should not be drawn tightly in order to prevent its cutting through the liver substance. A properly placed suture will effectively control a very active hepatic hemorrhage. The retained foreign body, if of considerable size, should be removed in order to avoid the subsequent complication of liver abscess. The shock present should be combated with heat administration of fluids, and adequate doses of morphine. When the loss of blood has been considerable and the hemorrhage is no longer active transfusion should be performed.

The mortality rate of liver wounds is 66.27 per cent.[1]

A considerable number of uncomplicated wounds of the liver treated expectantly get well. The cases of this type operated upon give a mortality of about 5 per cent;[1] the mortality rate to be expected if complicating lesions are encountered is in the neighborhood of the mortality rate for liver wounds as a whole. Certain of the cases with retained foreign body in the liver develop a hepatic abscess and may succumb to sepsis.

Wounds of the gall bladder and bile ducts are so comparatively infrequent that any special consideration of them will be omitted. Records of but 9 cases in the American Expeditionary Forces exist, with a mortality rate of 77.78 per cent.[1]

WOUNDS OF THE PANCREAS

The cases reaching the hospital comprise about 0.2 per cent of all abdominal injuries.[1] The proximity of the organ to the great vessels may give a rapidly fatal result upon the field of battle, so that a certain proportion of these cases never reach the hospital.

The accompanying lesions usually found are those of the stomach; other organs are much less frequently involved. The one important element to success is adequate drainage.

At least half of the cases prove fatal from an undiscovered or poorly drained injury. The writer had one case showing an anteroposterior wound in the epigastrium. Operation revealed a small shell fragment lodged in the head of the pancreas with an associated contusion but no penetration of the adjacent duodenal wall. The foreign body was readily removed, and wound in the pancreas drained, and the patient when last seen, seven days after operation, was convalescing satisfactorily.

WOUNDS OF THE SPLEEN

Wounds of the spleen are much less frequent than those of the liver, 49 only having been recorded as occurring in the American Expeditionary Forces.[1] Two-thirds of the splenic wounds show complicating lesions.

The injuries may be of all types, from a small perforation or moderate laceration to a complete separation of a considerable portion of the organ, or an avulsion from its pedicle. The visceral injury most frequently complicating a splenic wound is a lesion of the kidney; organs less often involved are the colon and stomach.

As with wounds of the liver, hemorrhage is the chief symptom along with the shock resulting from it. The intraabdominal signs of hemorrhage described under wounds of the liver apply equally to splenic wounds. The fluid, however, is more apt to accumulate in the left flank. The diagnosis is made from the position of the wound and the accompanying signs of hemorrhage and shock.

The best incision of approach is the left subcostal, but a left rectus incision may give adequate access. In some cases a liberal median or paramedian incision may give abundance of room. The incision for abdominothoracic injuries is dealt with in a subsequent paragraph. Where the hemorrhage is inactive and has not been of large amount abstention is the best rule to follow in an uncomplicated case. A small wound encountered at operation and showing no active hemorrhage should be left alone. Suture in the splenic tissue is less effective in controlling hemorrhage than in liver tissue, and a continuation of the bleeding is always a possibility. Packing in cases of this sort is desirable. Splenectomy, though advised by some writers, notably Depage,[15] gave practically a 100 per cent mortality in the American Expeditionary Forces.[1] The treatment of hemorrhage and shock is the same as with liver injuries.

The mortality rate is 63.26 per cent.[1] Hemorrhage is the cause of death in practically all the uncomplicated cases.

WOUNDS OF THE KIDNEY

Wounds of the kidney constitute 6.3 per cent of all abdominal injuries;[1] one-half of the cases are uncomplicated. Wounds of the right kidney are complicated by liver injuries in about one-third of all cases, and wounds of the left kidney are attended with splenic lesions almost as frequently. The hollow viscera most often wounded are the small gut or colon, while stomach lesions are less frequently encountered.

Wounds of the hilum include injuries to the renal vessels or to the pelvis itself. Wounds of the renal vessels are usually serious and often fatal because of the severe hemorrhage. It is well to bear in mind that an injury to any of the renal branches results in necrosis of that portion of the kidney tissue which the vessel supplies, as the anastomotic circulation of the kidney is very poorly developed. Injuries of the pelvis itself are comparatively rare and require no further discussion.

Wounds of the parenchyma may be of any type from a simple perforating or tangential wound to a very extensive laceration or destruction of the organ.

The X ray gives important aid in arriving at a correct diagnosis in this group of cases. Hemorrhage as well is an important symptom; the bleeding may occur from the external wound, it may appear in the urine, or may form a retroperitoneal haematoma. Bleeding into the peritoneal cavity may take place if the rupture has been intraperitoneal. Under such conditions one may expect a tender and rigid abdominal wall with dullness in the flank. Under any circumstance, if loss of blood has been considerable, the patient may exhibit symptoms of shock.

Leakage of urine is present when the pelvis of the kidney has been opened or the ureter has been torn, but seldom with wounding of the parenchyma itself.

Retention of urine is seen in a certain proportion of cases. Sepsis is a later complication, which may develop where inadequate drainage has been established or where hollow visceral complications have resulted in a fecal fistula into the wound. Cases with sepsis exhibit all the symptoms common to this condition. Vomiting is frequently seen. Out of 42 cases reported by Fullerton[16] arriving at a base hospital with kidney lesions 9 suffered a secondary hemorrhage; 1 on the third day, 1 on the seventh day, 5 between the tenth and fifteenth days, and 2 after four weeks.

Conservatism should be the keynote in the treatment of lesions of the kidney. With a penetrating rifle wound and where these is no evidence of intestinal involvement rest and a liberal administration of opium are indicated. Alarming hemorrhage, urinary leakage, advancing symptoms of sepsis, or a large retained foreign body are the principal indications for operative intervention. A complicating hollow visceral injury requires immediate operation. The incision of choice is a transverse or oblique one, which may be extended as far forward as is necessary to give adequate exposure of the kidney or to treat other complicating visceral injuries. If a small lacerated wound with a retained foreign body is encountered the removal of the missile and drainage may be all hat is necessary for a satisfactory recovery. Charles[9] advises under these

circumstances a débridement of the damaged kidney tissues, followed by suture and drainage. A rubber-covered clamp upon the renal vessels during this procedure gives satisfactory control of hemorrhage. If such dissection can be done with little sacrifice of kidney tissue it is a legitimate procedure. Nephrectomy should be avoided wherever possible, for in the push of advanced war surgery definite information as to the function of the other kidney must of necessity be lacking. Nephrectomy, however, must be performed where the vessels themselves are seriously damaged or where the injury to the kidney itself is extensive.

The mortality in uncomplicated cases varies from 25 to 30 per cent.[1] The fatal cases far forward succumb to hemorrhage. In the rear areas sepsis and secondary hemorrhage are the chief factors leading to death.

WOUNDS OF THE URETER

Wounds of the ureter are infrequent. A gross injury calls for nephrectomy. Where a small wound is encountered suture may be attempted, but, in general, ureteral wounds will heal spontaneously if left alone.

WOUNDS OF THE BLADDER

Injuries of this organ comprise approximately 5 per cent of all abdominal lesions and one-half of the cases are uncomplicated.

In Fullerton's[17] series 70 per cent of the cases were complicated by intestinal or bone injuries or both. A wound of the rectum may be expected in from 10 to 15 per cent of the cases. Injury of the prostate is comparatively rare.

Cathelin,[18] in a series of 29 bladder wounds, found that the entrance was placed posteriorly 18 times, anteriorly 7 times, and laterally in the remaining cases. A wound of exit was present in but 5 of the patients.

Bladder perforations may be caused by either the projectile or by bone spicules from the fractured pelvis. The lesion of the bladder may be extraperitoneal or intraperitoneal and may vary considerably in size. Legueu[19] reported 10 cases of fracture of the pelvis associated with bladder injury in which a vesical calculus was demonstrable. Other observers have not so uniformly encountered such conditions.

Hemorrhage in connection with bladder wounds is usually not serious, but its occurrence into the bladder suggests an extraperitoneal lesion. With this type of injury a considerable haematoma is not infrequently found in the vicinity of the wound in the viscus. Urinary discharge through the entrance wound is fairly uncommon. An empty bladder should make one strongly suspicious of an intraperitoneal perforation. Leakage of urine into the peritoneal cavity causes a considerable degree of peritoneal irritation with definite local signs.

Most of the extraperitoneal lesions result in pelvic cellulitis. In the long standing cases associated bone necrosis and calculus formation may be expected, and in most instances a cystitis still continues.

Extraperitoneal lesions are best treated by wide incision down to the bladder wound, which sould be sutured if possible. Ample drainage of soft

tissues must then be provided. Suprapubic cystotomy furnishes the best type of bladder drainage and should generally be employed.

The patients suffering from intraperitoneal wounds, and especially those with associated visceral lesions, show such decided symptoms that little doubt exists as to the wisdom of laparotomy. Such lesions require operation with suture of the bladder wound and rubber-dam drainage down to the stitch line. A retention catheter or perineal drainage, preferably the former, meets the indications; suprapubic cystotomy should be avoided if possible.

Retained missiles are fairly frequent in the bladder. The projectile must always be sought for within the bladder, and if present removed.

In the latter stages of bladder wounds one must consider the treatment of persistent urinary fistulæ, calculi, and sepsis. Cathelin's method of dealing with persistent fistulæ is an efficient one. He dissects a cuff of skin and infolds it by suture down to the bladder wall, later bringing muscle and aponeurosis over it. Calculi had best be removed by the urethra, with or without crushing, but a suprapubic cystotomy may be necessary. The treatment of sepsis is supportive but the cases usually result disastrously.

The presence of complicating injuries may require considerable modification in operative technique. If a rectal or colic injury is so extensive as to make a colostomy imperative a suprapubic cystotomy should be dispensed with.

Very variable statistics will be found in the literature concerned with the mortality rate following uncomplicated bladder wounds, but the average is about 50 per cent. Where the bladder injury is associated with a lesion of the small intestine a much higher figure is reached, running to 75 or 80 per cent. The causes of death are sepsis, general peritonitis, or, much more rarely, a secondary hemorrhage from the pelvic vessels.

An important prophylactic precaution in the avoidance of bladder wounds consists in an invariable order that soldiers should empty their bladder before going into action.

ABDOMINOTHORACIC INJURIES

These wounds comprised 4.6 per cent of all the thoracic injuries coming to the evacuation hospitals, American Expeditionary Forces, for treatment.[11]

The lesions encountered are thoracic, diaphragmatic, and abdominal. Duval,[19] gives the general rule that with a wound of entry in the chest the thoracic lesions are more apt to be the serious ones, while with entry through the abdomen the abdominal injuries are more often the graver ones. Frequently there are several wounds of the lungs and more than one lobe is occasionally involved. The types of lesion are the same as one encounters in simple thoracic wounds. A certain amount of hemothorax is always present, but the amount is variable. In approximately one-third of the cases a hollow abdominal organ is penetrated. An uncomplicated liver injury is more common than one of the spleen.

The wound in the diaphragm may be made either by the projectile or by a fractured rib. The diaphragmatic wound may vary from a small puncture to an irregular opening of large size; the shape is often slit-like, in which instance it

is usually not more than an inch long. In about 10 per cent of the cases herniated abdominal organs will be found in the chest cavity. The omentum is the structure most often seen, and if viscera are extruded into the thorax the omentum usually accompanies them. Next in order of frequency are the spleen, stomach, and transverse colon. Practically all herniations occur through a wound in the left side of the diaphragm.

Through-and-through wounds involving both sides of the diaphragm are seldom encountered in the hospital, for most of them die far forward before evacuation can be carried out.

The pathognomonic symptoms of abdominothoracic wounds are dyspnea, the breathing being rapid and labored; sudden pain in the abdomen at the time of the receipt of the wound; hemothorax; abdominal rigidity over the corresponding half of the abdomen, especially in its upper part; and shock, which is partially dependent upon the degree of hemorrhage and partially upon the respiratory distress. Other abdominal symptoms such as definite local tenderness and vomiting may also be evident.

Course of Treatment Dependent Upon Type of Injury

If there are separate wounds of entrance for the abdomen and chest and the latter one is not a blowing wound, the abdomen should be opened immediately if a hollow visceral lesion is suspected, and the chest should be left undisturbed. With a wound of entrance on the right side of the chest authors vary as to the procedure to be adopted. If the missile is a small one and X-ray examination localizes it in the liver the wisest course is nonintervention. If the chest wound is a blowing one it should be closed by suture in which the muscular layer is included. No blowing chest wound should ever be allowed to get past the regimental dressing station without a closure of the muscular layers of the wound by suture. This rule should be adhered to even if asepsis can not be maintained. Many advise operation in this group of patients, the steps being débridement of the chest wall, and exploration of the diaphragm and liver through an intercostal or vertical wound after the chest lesions have been cared for. The foreign body is removed from the liver when possible, the diaphragm sutured, and finally the chest itself closed without drainage.

With a wound on the left side above the level of the eighth rib and an associated abdominal injury which is high up a different problem is presented. Excellent constructive surgery has been developed by Duval [20] in cases of this type. He uses a vertical incision upon the chest wall, beginning near the thoracic wound. The ribs are sectioned in order to allow access to the thorax, and the prolongation of the wound downward opens the abdomen; at times this lower extension may be continued obliquely forward. Other surgeons employ a transpleural approach to the upper abdomen with an incision which is roughly transverse. A rib may be resected, or access may be had through an intercostal space with the aid of Lilienthal's rib spreader. The chest wound is carefully dissected out and any soiled rib or loose bone fragments are removed. With fresh instruments the pleural cavity is explored and any lesions encountered are taken care of. The wound in the diaphragm is then sought for and enlarged up to 5 or 6 inches; this exposure gives a satisfactory

approach to the abdomen. Any abdominal injury found is cared for and the diaphragm closed. It is generally wise to obliterate the pleural space low down by suturing the diaphragm to either the lung or the lateral pleural wall. The chest should be closed without drainage.

With a wound on the left side and the point of entrance below the eighth rib the lesion within the abdomen is apt to be more serious. In this group of cases the abdomen should first be dealt with through a separate incision. At times it is possible to deal properly with the opening in the diaphragm from below. If the pulmonary injury warrants intervention it may be explored through an intercostal space. The closing off of the pleural cavity is accomplished as described in the preceding paragraph.

Duval to the contrary notwithstanding, the mortality rate is principally due to the lesion in the abdomen, and is distinctly higher when a hollow viscus has been penetrated.

LESSONS IN CIVIL ABDOMINAL SURGERY GAINED FROM THE WAR

The contributions of the war to civil abdominal surgery may be summarized as follows: (1) It has shown the types of tangential wounds which are not infrequently without visceral lesions. (2) It has taught the unwisdom in most cases of relying upon the so-called expectant treatment of abdominal wounds and the soundness of early radical operation. (3) It has demonstrated the wisdom of waiting an hour or so before operation is attempted in cases with severe shock. This rule applies, of course, only to those instances where shock is not due to active hemorrhage. (4) It has taught us the best methods of handling abdominothoracic injuries. (5) It has given an unusual opportunity to review the whole subject of abdominal drainage, strengthening our convictions that the general peritoneal cavity can not be drained, but that it is possible to drain a single focus within the peritoneal cavity. (6) It has emphasized again and again that speed, dexterity, simplicity of technique, and the minimum of traumatism are essential to success.

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CHAPTER XVI

WOUNDS OF THE GENITOURINARY TRACT

Shortly after the establishment of the American Expeditionary Forces a manual of urology[a] was prepared and distributed to the Medical Department, A. E. F., with the view of standardizing, among other activities, the work of those medical officers in whose hands would fall cases requiring operative treatment for injury to the genitourinary tract, incident to battle.[1]

Since the text of this manual, in so far as the present subject is concerned, was based upon the existent literature, and since it proved of value in the work of medical officers, especially consulting urologists, it has been largely drawn upon in the preparation of this chapter.

It is unfortunate that analytical studies of series of injuries to the genitourinary tract could not have been made on cases while these were in hospital. Lacking these, recourse has been had to clinical records, which, being variously prepared, frequently are silent as to features that would have present value.

WOUNDS OF THE KIDNEY

Wounds of the kidney in war are neither infrequent nor unimportant. It is true they are overshadowed in many instances by the more frequent and fatal lesions of adjacent viscera and so are frequently overlooked. But since they in themselves, though often fatal, are singularly amenable to intelligent treatment, the surgeon should not fail to focus his attention upon them.

In 2,385 gunshot wounds of the abdomen in the American Expeditionary Forces, the kidney was involved in 129 instances, a percentage of 5.44.[2] To determine the relationship of the kidney injury with those of other organs, the clinical records of 66 members of the American Expeditionary Forces,[3] showing injury to the kidney, were analyzed. In 38 instances no other viscus was involved. The association of lesions of other viscera was as follows: Liver, 11; spleen, 5; small intestine, 3; large intestine, 6. Thoracic viscera were injured in 11 instances in association, 2 of which are included above in connection with injuries of abdominal viscera.

As to the nature of the missile, in 61 of the cases this was given as follows: Rifle and machine gun, 41; shrapnel and high-explosive shell, 20.

PATHOLOGY

A gunshot wound of the kidney itself may involve only the parenchyma, one of the larger renal vessels, or the pelvis. If the parenchyma alone is injured and the pelvis scarcely opened, the resulting microscopic hematuria may pass

[a] The Manual of Urology for the Medical Department, A. E. F., was prepared by the author of this chapter in collaboration with Maj. Edward L. Keyes, Capts. M. L. Boyd, Everard L. Oliver, W. H. Mook, and D. M. Davis, and Lieuts. J. E. Moore and William Jack, M. C.

unnoticed and the renal injury either escape detection altogether or be disclosed by operation for other injuries or by a lumbar hematoma. If an artery is divided or so contused as to become obstructed by clot, the renal parenchyma supplied by this vessel will become gangrenous, for the arteries of the kidney are terminal; they do not anastomose. Division of one of the main branches of the renal artery, near the hilum, usually results in hemorrhage so severe as to demand operation, probably nephrectomy. Wounds of the renal pelvis of themselves imply only extravasation of urine, but, like those of the renal vessels, they are almost always associated with wounds of the renal artery and of the adjacent viscera as well.

The wound in the parenchyma may be perforating, tangential, or explosive. The edges of the wound are usually contused; adjacent parenchyma may become necrotic through arterial injury, but the more remote portions of the parenchyma suffer no more than temporary congestion, expressed by a brief anuria.

The later lesions are those of infection and extravasation, intraperitoneal or extraperitoneal. Destruction of fascial planes eliminates the usual anotomical restriction to their spread.

CLINICAL PICTURE

The patient arrives at the evacuation hospital labeled as a wound of the buttock, thigh, abdomen, or chest. The surgeon's immediate concern is with the state of shock, the amount of hemorrhage, the length of time since the patient was wounded, the general character of the wound itself, and symptoms pointing to perforation of the intraperitoneal viscera.

Unless the situation of the wound itself, the presence of hematoma in the loin, or of blood in the urine call his attention to the probable existence of a kidney injury, this does not usually enter the surgeon's calculations, since injuries to the other abdominal or the thoracic viscera are of much more immediate importance and are far more common, the decision to operate or not to operate is also reached with reference to the patient's general condition and the presence of a "penetrating" wound rather than with reference to a kidney injury.

SYMPTOMS

The immediate symptoms of renal wounds are due to hemorrhage. Thus hematuria is absent only if the ureter is completely divided or obstructed by clot, or if the wound does not invade the renal pelvis. This hematuria is total, but usually not so severe as to cause clotting in the bladder. Retention of urine is common. Shock is not so severe as that due to intraperitoneal injuries, unless the patient is exsanguinated. It is noteworthy that the hemorrhage from renal injuries, however severe, is rarely fatal. Hematoma in the loin develops rapidly in wounds that do not drain freely. It excites tenderness and rigidity of the overlying muscles, and forms an ill-defined mass. Hemorrhage from the wound is free. Intraperitoneal hemorrhage is obscured by the symptoms due to lesions of other organs. Gas gangrene, sepsis, extravasation, and secondary hemorrhage are the causes of death at the base. Secondary

hemorrhage may occur as late as two months after the wound. It is quite common in the second and third week. It is more to be feared than the primary bleeding because of its severity and its marked tendency to recur, from each of which recurrences the patient rallies less well than from its predecessor. Renal infection and stone are late complications.

DIAGNOSIS

All patients with abdominal injuries should be catheterized at the first opportunity, unless they can urinate freely. The urine obtained should be examined for blood.

Large wounds of the loin present no special diagnostic difficulties. The diagnosis is obscure under two conditions: (1) In the presence of hematuria. If the wound gives no clue as to the source of bleeding the diagnosis is made by cystoscopy, which discloses blood from the ureter, or by exploratory operation undertaken for the relief of other visceral lesions. (2) In the absence of hematuria. The renal injury is disclosed by cystoscopy and ureteral catheterization; operation for hematuria; retroperitoneal infection; lesions of other viscera.

Ureteral wounds seemingly do not occasion sufficient bleeding to permit an immediate diagnosis, except by surgical exploration.

TREATMENT

AT THE FRONT

When there is doubt as to whether or not to open the belly or the loin first, the loin should be opened. The loin incision should be transverse and extend approximately to the edge of the rectus. It may be enlarged by a vertical transrectus incision or by a vertical incision along the outer border of the erector spinæ muscle long enough to permit division of all muscular and ligamentous attachments to the last rib. The twelfth dorsal nerve and artery may be avoided by placing the transverse incision a finger's breadth below the rib. Thus also one avoids the danger of inadvertently entering the pleura, through mistaking the eleventh for the twelfth rib.

If there is a wound of the loin and hematuria, or if the wound plainly leads to the kidneys, enlarge it transversely, deliver the kidney and examine the hilum for lesions of the renal vessels.

If the main artery or vein, or the upper main branch of the artery, are wounded, perform nephrectomy. If smaller arteries or the lower branch of the renal artery are wounded, or the renal wound is a relatively slight one, there are three procedures: (*a*) For wounds that are not very extensive or ragged and do not involve any great destruction of the arterial system of the kidney it may be wise to do nothing more than to pack the loin wound down to kidney. (*b*) But in case of persistent hemorrhage, extensive contusion, presence of foreign bodies, or division of arteries, the kidney demands the surgeon's attention; the renal wound may be packed or a portion of the parenchyma excised and sutured. (*c*) At the evacuation hospital, where such primary operations are usually performed, conditions are often such as to prohibit prolongation of the

operation for the purpose of resecting and suturing the kidney or searching for shell fragments or bullets. Resection is, however, the ideal operation for such cases—an ideal which has been realized in a few cases and one which the surgeon should always bear in mind. When partial nephrectomy is performed the excised portion should include all that part of the kidney parenchyma which is deprived of circulation by division of its artery.

If this has been opened, a small tube should be left in the pelvis of the kidney two days, in order to evacuate blood clots and to hasten the return of kidney function by removing intrapelvic pressure. Always open peritoneum in front of the colon in order to examine the adjacent viscera. Drain and suture the wound in the usual manner.

Complete nephrectomy should be performed when more than one-third of the kidney is contused. On the other hand, when less than one-third is contused resection may be considered.

If hematuria suggests renal injury, but the wound is remote from the loin, the decision in favor of or against immediate operation should be based on the following data: If the patient is going to die of primary renal hemorrhage, he is likely to do so before reaching the dressing station. Though exploration of renal wounds usually starts a fresh parenchymatous hemorrhage, it discloses the fact that the primary bleeding has already stopped. Therefore unless an external wound leads directly to the kidney region the presence of hematuria or of a retroperitoneal hematoma is no indication for immediate operation. A retroperitoneal hemorrhage discovered in the course of a laparotomy may be disregarded (it often does not arise from the renal vessels at all) unless it is of enormous size, in which event it should be evacuated extraperitoneally, before the intestines are much handled, for it has been found that immediate grave shock results from turning the patient over and operating upon his loin after laparotomy.

Transperitoneal nephrectomy is generally condemned.

AT THE BASE

All secondary operations should be preceded by cystoscopy, to ascertain the condition of the opposite kidney, and fluoroscopy to locate fragments of bone or missile. Large hematomata should be evacuated to forestall infection. Secondary hemorrhage calls for transfusion and, usually, for prompt nephrectomy unless other complications prohibit this, for the hemorrhage is likely to recur and the effect of each return of bleeding is cumulative. Sepsis is combated according to general principles of drainage and antisepsis. Persistent urinary fistulæ in the loin should be treated by the insertion of a ureteral catheter up to the pelvis of the kidney. The catheter may be left in place for an indefinite period if changed every fourth or fifth day. If healing is to occur this may be expected within 10 days.

If the fistula fails to heal, the kidney may be explored for the purpose of reestablishing this urinary flow by plastic operation, or for nephrectomy, if the opposite kidney is proved sound.

MORTALITY

The mortality rate of injuries to the kidney, both complicated and uncomplicated, proved to be 55.81 among cases of the American Expeditionary Forces treated in hospital.[2] The clinical record of 66 cases showed a mortality of 50.[3]

To shock and hemorrhage may be attributed a certain number of deaths in kidney injury at the front. However, with improvements in evacuation, so as to hasten the arrival of the wounded at hospital, and improvement in methods of treating shock, obviously danger from the above-mentioned causes of death was lessened. Thus, of 37 of the series of 66 cases mentioned above, 28 were operated upon on the day of injury; eight, on the second day; one, on the third day. In a series of 13 cases, in hospitals at the front, 3 died and 10 were evacuated to the base.[4]

When we consider the frequency of involvement of other important organs, the percentage of fatalities is not surprising. In the series of 66 cases, the intestines were involved in 14 per cent; liver, 16 per cent; chest, 16 per cent; peritoneal cavity, 39 per cent.[3]

CASE REPORTS

Case 1 R. H., sergeant, Company F., 355th Infantry, A. E. F. Gunshot wound of back, left kidney, received in action October 21, 1918. Evacuation Hospital No. 10: Through-and-through wound of back; wound of entrance, left post axillary line; wound of exit, right post axillary line. Urinary retention; catheter showed blood in urine. Base Hospital No. 15: During night of October 27, severe hemorrhage into bladder. Patient became pulseless. Salt solution infusion. Cystoscopy showed bleeding from left kidney. Left lumbar nephrectomy, suprapubic drainage of bladder. Base Hospital No. 6: December 15, 1918. Gunshot wound of back, perforating left post axillary line to right back, nephrectomy wound, left loin, suprapubic wound, bed sore, paralysis below waist line, bladder satisfactorily drained by putting large catheter in place of suprapubic tube. Ultimate result, cure.

A. E. F. Records

Case 2. J. E. H., 1204342, Company L, 105th Infantry. Wounded August 5, 1918. Gunshot wound of side, penetrating abdomen, causing tear of ascending colon and damage to lower pole of right kidney. Operation, Canadian casualty clearing station, several hours after injury: Suture of intra and extraperitoneal tear of ascending colon. Liver and kidney sutured. Removal of foreign body from liver. Drainage. Tedious convalescence. Ultimate recovery. Demobilized January 8, 1919, 10 per cent disability.

Case 3. J. G., Company D, 120th Machine Gun Company, 273042. Wounded October 8, 1918. Gunshot wound entering right lumbar region, penetrating lower pole of kidney. Wound of colon. Operation, same day: Laparotomy, suture of colon and mesentery, drainage of right kidney, débridement. Foreign body removed. November 19, 1918, second operation for intestinal obstruction due to adhesions. January 29, 1919, cystoscopy, ureteral catheterization and functional tests negative. February 7, 1919, duty. February 18, 1919, demobilized; disability, 50 per cent.

Case 4. H. C., 101333, Company G, 168th Infantry. Wounded September 12, 1918. Gunshot wound, abdomen, rupture of left kidney. Operation, 10 hours later: Laparotomy, no intestinal injury found; closure; dorsal incision; kidney delivered; 3 clamps applied; kidney removed. Recovery. March 6, 1919, duty. March 13, 1919, demobilization, 50 per cent disability.

Case 5. E. M. P., 76925, shrapnel wound. Gunshot wound, right lumbar region, hip, right kidney, and left shoulder. Resection of colon. Operation, same day: Débridement, foreign body removed, right kidney perforated, drainage. February 5, 1919, nephrectomy,

right. Pyonephrosis. Fistula connecting hepatic flexure of colon to pyonephritic sac. March 20, 1919, duty. April 22, 1919, demobilized, 75 per cent disability.

Case 6. C. A. B., 57153, Company D, 28th Infantry. Wounded July 21, 1918. Gunshot wound, penetrating upper right abdomen; fracture of eleventh and twelfth ribs; injury to liver and kidney. Operation. Record of first operation lost. August 8, 1918, abdomen drained. November 30, 1918, nephrectomy, right; complications: Urinary fistula from right kidney, multiple abscesses, arthritis, sinus tract of abdominal wall. July 23, 1919, demobilized, disability 75 per cent.

Case 7. H. J. K., Machine Gun Company, 356th Infantry, 3173056. Wounded September 12, 1918. Gunshot wound, chest, penetrating right back at eleventh rib, perforating kidney and liver. Operation, nephrectomy. January 30, 1919, demobilized, disability 40 per cent.

Case 8. E. K., 2858609. Wounded September 12, 1918. Gunshot wound, right side, passing through diaphragm, liver, and kidney. Operation, laparotomy. Considerable blood found in cavity; small injury to kidney, inaccessible. Drainage of abdomen. Foreign body removed from back, subcutaneously. Complication: Bronchopneumonia. February 11, 1919, to duty, convalescent center. January 15, 1920, demobilized, 30 per cent disability.

Case 9. M. F. B., Company E, Seventh Engineers. Wounded September 17, 1918. Gunshot wound, left lumbar region over left kidney, bullet lodging in kidney. Operation: Foreign body removed from left kidney through extraperitoneal incision. Recovery. December 25, 1918, duty.

Case 10. V. R., 1317456. Wounded September 29, 1918. Gunshot wound, back, penetrating right kidney. Operation: Débridement, drainage. September 30, 1918, passing blood in urine. October 13, 1918. Operation: Eighth rib resected, liver drained; foreign body removed from right back. January 25, 1919, nephrectomy, right. June 16, 1919, demobilized, disability, 25 per cent.

Case 11. J. McK., 1207623. Gunshot wound, left loin, penetrating kidney and diaphragm. Operation, same day: Foreign body removed from upper surface of diaphragm, which was sutured. Kidney drained. Recovery. March 6, 1919, demobilized, no disability.

Case 12. A. F., 3495499, Company D, 165th Infantry. Wounded October 16, 1918. Gunshot wound, penetrating peritoneum and injuring kidney. Operation: Débridement, drainage. Recovery. November 14, 1918, operation: Resection of rib for empyema. July 5, 1919, demobilized, disability, 30 per cent, on account of old suppurative pleurisy and obliteration of lung.

WOUNDS OF THE URETER

The brief mention of wounds of the ureter in medical periodicals throws little light upon the subject. There are records of four gunshot wounds of the ureter in the American Expeditionary Forces.[2] Apparently the wound has always been associated with visceral injury requiring abdominal section. The ureteral lesion is disclosed by the watery quality and urinous odor of the intra or retroperitoneal drainage, or else by appearance of urine in the dressings after operation.

The treatment is expectant. Several such urinary fistulæ have healed spontaneously.

In brief, the treatment of ureteral wounds is the following:

Immediate repair by suture of the wound, if it is reparable and if the patient's condition permits.

If these conditions can not be fulfilled, adequate drainage will be provided for the urine. The upper end of a completely severed ureter which can not be repaired may be brought up and sutured to the parietes. Primary nephrectomy is not to be considered because of the added danger to life.

If the ureter is sutured the finest chromic gut should be employed, for plain catgut will not hold. But great care must be taken to catch the ureter at its very cut edges so that as little as possible of the suture remains within the lumen of the canal, for fear of secondary stone formation. A small drain should be led down to the ureteral wound.

If the completely divided ureter is dislocated and sutured to the parietes, no tension whatsoever should be made upon it for fear of angulation. A few strands of silkworm gut left in the ureter will greatly facilitate the urinary drainage.

If the ureter is known to be irreparably divided, nephrectomy is the operation of choice, after the patient has rallied from the immediate effects of his injury and catheterization of the ureter has proved the opposite kidney sound.

If the opposite kidney is not sound, a cup should be fitted over the ureteral fistula and permanent drainage established.

If the wound is not known to be irreparable, a precise diagnosis should be established by pyelography; if possible the kidney should be drained by the indwelling ureter catheter. The failure of ureter catheter drainage indicates the necessity for operative treatment. While it may be possible in certain instances to reestablish drainage by plastic operation, such procedures are notoriously inefficient in the treatment of infected kidneys, and the masses of scar resulting from the wound would doubtless still further diminish the probability of success. Nephrectomy will usually be required.

The following case, reported by Stevens, concerns a ureteral injury:[5]

Case 13. Gunshot wound, penetrating, of back; hematuria; bullet removed through perirectal incision. Patient was admitted with hematuria. Gunshot wound of the back above right costal margin; no wound of exit. Cystoscopy showed blood coming from the right ureter, but urethral catheter, which was passed up to the renal pelvis, gave clear urine, miscroscopically free from blood. Roentgen-ray examination showed machine-gun bullet lodged in the bony pelvis back of bladder in region of lower pole, right ureter. On rectal examination, missile could be felt high up in this region. Fluoroscopic and X-ray examinations with catheter in ureter showed that bullet had probably injured the ureter. Through a ateral perirectal incision bullet was removed without difficulty.

WOUNDS OF THE BLADDER

In the experience of the American Expeditionary Forces, battle injuries to the bladder bore about the same ratio to abdominal wounds as did injuries to the kidney; that is to say, of 2,385 abdominal injuries, 127 involved the bladder, a percentage of 5.32.[2]

In a series of 57 cases,[3] rifle and machine-gun missiles injured the bladder in 46 instances; shrapnel and high-explosive shell, in 11. There is no record of piercing instruments causing injury to the bladder in the American Expeditionary Forces.[2] In the series referred to, the abdomen was involved in 17 instances; the rectum, in 5; large intestine, in 4; small intestine, in 15.

CHARACTER OF INJURY

The size and shape of the bladder perforation depend upon the type of missile producing the wound. The perforation varies from the small slitlike hole of the rifle missile to the large laceration of the shell fragment. Small

missiles may destroy very little of the bladder substance, but larger ones may destroy a very considerable portion of the bladder wall.

The projectile may enter the bladder from any angle, and entrance wounds high up in the abdominal wall or back, and wounds of the buttocks, thighs, and hips, or of the perineum, may involve the bladder, and should always be viewed with suspicion, as it is often impossible from the position of the wound of entrance to tell whether or not the bladder has been injured. It is wise always to consider the possibility of vesical wounds in doubtful cases.

Foreign bodies, such as bits of clothing and spicules of bone have been carried into the bladder by the projectile, and the missile itself has sometimes lodged there. If not removed, these foreign bodies become nuclei on which stones may form.

Experience of the World War has gone far to eliminate the classic distinction of injuries to the bladder whereby they are divided into two groups, the intra and extraperitoneal. In the description of symptoms and treatment, however, the distinction of extra and intraperitoneal injuries must be maintained for the sake of clarity. But in the field the surgeon will find that most of the intraperitoneal bladder wounds are associated with extraperitoneal wounds and that the diagnosis of extraperitoneal injuries founded upon the absence of abdominal tenderness and rigidity may ultimately be belied by a fatal peritonitis. The following classification therefore simply represents the various combinations which may occur, and artificially dissociates the complex pathological conditions resulting from wounds of the pelvis or abdomen that involve the urinary bladder.

- I. Intraperitoneal injuries.
  - (A) Wounds.
    - I. Uncomplicated.
    - II. Complicated by—
      - (*a*) Perforations of other viscera.
        - 1. The small intestine.
        - 2. The colon.
      - (*b*) Fractures or injuries of bones.
      - (*c*) Injury to large blood vessels.
  - (B) Ruptures by concussion.
    - I. Complicated.
    - II. Uncomplicated.
- II. Extraperitoneal injuries.
  - (A) Wounds.
    - I. Uncomplicated.
    - II. Complicated by—
      - (*a*) Injury to rectum.
      - (*b*) Injury to deep urethra or prostate.
      - (*c*) Fractures of the bony pelvis or femur.
      - (*d*) Injury to important blood vessels.

INTRAPERITONEAL WOUNDS

Intraperitoneal wounds of the bladder are almost invariably associated with other intraperitoneal injuries, perforation of the small intestine being the most common. Owing to this frequent association no laparotomy should be regarded as complete until the bladder has been inspected on the operating table.

SYMPTOMS

Symptoms vary according to the position and size of the lesion and they depend considerably on lesions to other organs, especially the small or large intestine.

The outstanding subjective symptom of a bladder injury is a desire to void urine and an inability to do so. Often the patient is able only to expel a small amount of bloody urine. Frequently, however, no urine can be passed, since a large part of it is escaping into the abdominal cavity. Hematuria is always present. The amount of blood in the urine varies greatly. Usually it is present in considerable amount, though sometimes it is only visible as a smoky cloud. In case bleeding is profuse large intravesical clots form. Intestinal contents, especially in cases associated with rectal wounds, have often been noted in the urine drawn by catheter.

Symptoms referable to the abdomen are often very indefinite. There are signs of slowly developing peritonitis, namely, tenderness, rigidity, and dullness, at first limited to the lower abdomen. Later, this becomes general and the whole abdomen is tender and rigid. At this state there is usually nausea and vomiting. As the urinary collection in the peritoneal cavity increases, signs of intra-abdominal fluid appear; i. e., there is shifting dullness in the flanks and marked general abdominal distension.

DIAGNOSIS

Preoperative diagnosis can not usually include a cystoscopy and therefore can be but approximate. The hematuria indicates an injury to the urinary organs. The wounds of entrance and exit, the presence or absence of abdominal rigidity and tenderness, and the signs of injury to other viscera will suggest the location of this injury; that is, whether of the bladder or kidney, or whether intraperitoneal, extraperitoneal, or both. Under no circumstances should fluid be forced into a bladder through a catheter to determine whether or not it is ruptured. The consensus of surgical opinion is that such a procedure is both deceptive and dangerous.

TREATMENT

The peritoneal cavity is opened by a vertical incision through the rectus muscle and intestinal injuries are located and repaired. With the patient in the Trendelenberg position a finger is introduced through the perforation into the bladder to search for blood clot and foreign bodies, which if present are removed, and to locate the presence and position of any extraperitoneal tears. The hole in the bladder may be punctiform and easily closed by a purse-string

suture. The tear may be of considerable size and the method employed in repairing it will depend upon its position in the bladder wall. Wounds of the summit or anterior surface of the bladder are usually readily accessible. The edges of the bladder wound should be excised so that fresh surfaces may be brought together by a continuous suture of catgut approximating the muscular walls. A retention catheter should then be introduced. If the wound is situated at the base of the bladder it may be quite impossible to suture it. In such instances the best one can do is to convert the intraperitoneal wound into an extraperitoneal one by closing the peritoneum and carrying out suprapubic cystotomy.

Suprapubic cystotomy should not be done as a routine in these cases, as practically all authorities state that tight closure of the bladder and catheterization is preferable. Catheterization is usually necessary for only four or five days.

PROGNOSIS

The mortality of intraperitoneal wounds of the bladder varies between 50 and 70 per cent. Peritonitis secondary to intestinal perforation is an important cause of death. Perforations of the posterior bladder wall have been overlooked and a urinary extravasation into the peritoneum has led to subsequent peritonitis and death. Unquestionably the immediate mortality cases where large blood vessels have been severed by the missile, has been very high.

EXTRAPERITONEAL WOUNDS

Wounds of the buttocks, thighs, or hips, with little or no evidence of any abdominal disturbance or discomfort, frequently invade the bladder extraperitoneally and should always be carefully investigated. Sacral and perineal wounds involving the rectum have often an associated bladder injury of this type, while wounds of the lower abdominal wall or flanks may obviously cause an extraperitoneal bladder perforation. These wounds of the bladder rarely exist independently.

In a series of 35 cases of extraperitoneal injury to the bladder,[3] there was an associated involvement, in 8, of either the bony pelvis or the femur. In three instances, the rectum was injured; in one, the prostate was injured.

Intraperitoneal perforations are frequently produced by a missile entering the bladder extraperitoneally. Thus, in a series of 44 such cases,[3] the small intestine was injured in 8 instances, the large, in 1.

SYMPTOMS

An uncomplicated extraperitoneal wound of the bladder produces hematuria and difficult urination; the signs of urinary extravasation are present. In these cases the urinary extravasation usually follows the path of least resistance, which is along the most damaged fascial planes. The wound of entrance may be of sufficient size adequately to drain the bladder and in these instances no extravasation into the tissues takes place. Severe cellulitis and sepsis follow in the wake of the urinary extravasation and often prove fatal.

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DIAGNOSIS

The diagnosis without cystoscopy can not be absolute. All patients with wounds of the buttocks or thighs should be catheterized. Hematuria will give a valuable hint as to the presence of bladder injury. Urine and blood may be draining from the wound of entrance. There may be associated intraabdominal lesions and the signs and symptoms of intestinal injury should always be looked for. In cases where the rectum and bladder have both been injured the urine will usually contain feces as well as blood.

TREATMENT

Urinary drainage must be provided for these cases, and the wound of the bladder wall repaired if accessible.

Urinary drainage may be provided by (1) cystotomy, (2) interval catheterization, (3) retention catheter, or (4) enlargement of the wound of entrance and drainage of the bladder through it. Some surgeons believe that cystotomy should be done for all bladder perforations. Others, however, believe that in many extraperitoneal bladder wounds satisfactory drainage can be obtained through the wound of entrance. Whereas, in 45 cases in the series of 57 bladder wounds were drained, cystotomy was done on but 14.

In general, it may be said that if the tract of the missile is short and fairly large the bladder can be properly drained through it and there is no need for suprapubic cystotomy. In cases where the missile has produced a long tract, satisfactory drainage can not be obtained through it. In wounds of the bladder complicated by compound fracture of the pelvis or femur, cystotomy should be employed as a routine. If urine is allowed to drain over these open fractures serious cellulitis results and sepsis develops, often leading to a fatal outcome.

MORTALITY

There were 68 deaths in the 127 cases of gunshot wounds of the bladder, American Expeditionary Forces.[2] The individual records [3] of but 57 cases have been discoverable. Among these, 35 deaths are recorded; 25 give no cause; 2 were from hemorrhage; 3 from shock; 3 from septicemia; 2 from pneumonia.

CASE REPORTS

Case 14. A. S., 3489070, Company G, 47th Infantry. Wounded October 12, 1918. Gunshot wound, penetrating right buttock, pelvis, and bladder. Shrapnel. Operation: Suprapubic cystotomy; foreign body not removed. Débridement and drainage of buttock. Ligation of sciatic artery. Débridement of wounds of arm. Complications: Gas gangrene of arm, necessitating amputation below shoulder. August 15, 1919, demobilized, 80 per cent disability, because of amputated arm. Healed scars, suprapubic and gluteal.

Case 15. M. C. G., 102628, Company M, 167th Infantry. Wounded July 28, 1918. Gunshot wound of abdomen between umbilicus and pubis, perforation of intestine and of bladder. Operation, July 29. Wound, débrided, two perforations in small intestine closed. Bladder wound closed with drainage. Recovery. February 27, 1919, operation to cure postoperative hernia. May 15, 1919, demobilized, 20 per cent disability, because of weakness of abdominal wall.

Case 16. E. D., 184581, Headquarters Company, 101st Engineers. Wounded November 9, 1918. Gunshot wound, penetrating abdomen in right lower quadrant, perforating

bladder and intestine. Operation, foreign body removed; bladder drained; perforation of intestine and bladder closed by suture. Details of operation lost. May 7, 1919, cystoscopy, small stone in bladder. July 14, 1919, demobilized, 30 per cent disability, because of hernia in abdominal wound.

Case 17. McK. G., 1380683. Gunshot wound entering left buttock, passing through intestine and bladder. Operation same day. Resection and end-to-end anastomosis of injured small intestine. Suture of wound in bladder. Recovery. October 6, 1918, removal of foreign body. December 25, 1918, returned to duty.

Case 18. J. H., 1415627, Company F, 165th Infantry. Gunshot wound, through and through, of sacrum, lower abdomen, bladder, right anterior abdominal wall, 7 cm. below umbilicus. Operation, incision; insertion of drainage tubes in front and behind. August 1, 1918, tube removed from lower abdominal incision, urine escapes. Able to void urine through urethra. October 5, 1918, wound healed, scars firm. November 10, 1918, return to duty.

Case 19. L. V. G., 1417607, Company D, 102d Infantry. Gunshot wound entrance, right buttock, passing through ilium, perforating bladder and left groin. Pubic bones fractured. Operation, November 18, 1918, median line abdominal incision. Omentum in hernial canal ligated and excised. No intestinal perforation found. Abdominal wound closed without drainage. Hernial sac excised. Wound closed. Drainage tube in bladder through tract of bullet. Recovery. November 10, 1918, a suprapubic drain inserted. November 21, 1918, external urethrotomy. Suprapubic fistula closed. December 20, 1918, No. 20 sound passes without difficulty. Wounds healing. Complications: Periurethral abscess, urinary fistula of lower abdomen. January 26, 1919, wounds healed. Demobilized, 50 per cent disability, because of wound of abdomen perforating bladder.

Case 20. W. J. D., 1456617, Company E, 139th Infantry. Wounded September 27, 1918. Gunshot wound penetrating the abdomen just above and to the right of the symphysis pubis, perforating bladder and rectum, the exit being through the center of the left buttock. Followed by a discharge of urine through wound of entrance and feces through wound of buttock. Operation, insertion of drainage tube into the bladder through the wound of entrance. November 7, 1918, urethral drainage provided. November 14, 1918, no leakage from abdominal wound. Slight discharge from sinus in buttock, but not of fecal character. January 20, 1919, culture from bladder urine showed no growth. May 17, 1919, demobilized, 15 per cent disability because of cicatrices and weakened abdominal muscles. No fistulæ.

Case 21. R. K., 106426, Company D, 3d Machine-Gun Battalion. Wounded August 18, 1918. Gunshot wound, right thigh, entering bladder. Operation, incision of wound of thigh, evacuation of hematoma of right buttock; suprapubic cystotomy, removal of foreign body in bladder; drainage. Recovery. Complications: Indirect inguinal hernia; operation therefor April 22, 1919. May 23, 1919, returned to duty.

Case 22. D. N., 2239852. Gunshot wound, through and through, of abdomen, perforating intestine and bladder; exit, right buttock. Urine and feces escaped through the wound. Operation. Wound of entrance débrided to peritoneum; closed with external drain of rubber tissue. Wound of exit débrided with cigarette drain inserted through the sacrum. Dakin tubes inserted in buttock wound. Laparotomy, median incision. Examination showed bullet had not passed through adbomen. Wound closed in layers. October 6, 1918, urine escaped from drainage incision in lower abdominal incision and fecal matter from right buttock wound. December 19, 1918, examination of fecal fistula showed opening into rectum 2 inches above internal sphincter. December 31, 1918, pelvic abscess pointed just to the inner side of the anterior superior spine, incised and drained. November 19, 1919, abdominal exploration, removal of Beck's paste from fistulous tract. Tube drainage provided. No further record.

Case 23. F. H. C., 2715115, Company D, 315th Infantry. Gunshot wound, penetrating, left thigh, pelvis, and bladder. At operation, laparotomy, the foreign body was removed from the pelvis, and perforation of bladder closed. Suprapubic drainage afforded. Complications: Left foot drop from injured sciatic nerve; urinary fistula, which finally healed. February 16, 1920, demobilized, 40 per cent disability because of paralysis of extensor muscles of left leg.

Case 24. R. B., 2846210, Company K, 355th Infantry. Gunshot wound, through and through, lower abdomen, perforating pubic bone and bladder; exit, right buttock. Laparotomy was performed the day of injury; examination showed perforation of bladder; no other viscera injured. Pubis was fractured; fragments removed. Bladder wound closed, rubber drainage tube inserted through wounds at entrance and exit. Subsequently vesicorectal fistula was discovered and on February 25, 1919, operation was done for this, successfully. May 27, 1919, demobilized, 15 per cent disability because of scars; no fistulæ present.

WOUNDS OF THE POSTERIOR URETHRA AND PROSTATE

Wounds of posterior urethra and prostate, like those of the bladder, are usually one element in an extensive wound of the pelvis or the thigh.

The usual injury is an extensive laceration of the urethra by a bullet or shell fragment. The missile in traversing the pelvis may fracture this or the femur, and lacerations of the rectum and bladder and pelvic vessels are common complications.

The usual symptoms of wound of the urethra is retention of urine, though if the wound is a large one, carrying away the neck of the bladder, there may be incontinence of urine.

Urethrorrhagia is an almost constant symptom. If the wound is transverse and does not lacerate the superficial tissues of the perineum, the injury to the urethra is disclosed by a perineal hematoma and confirmed by the passage of a catheter. If the urethral wound is neglected, the retention is soon exchanged for incontinence by overflow of the bladder, with resulting urinary infiltration and infection of the perineum, the ischiorectal fossæ, and the whole pelvis. Only the mildest injuries escape this fate.

The associated shock, hemorrhage, fracture of the pelvis, and wounds of rectum, bladder, or other viscera should not distract the surgeon's mind from the urethral condition. Whenever there is a fracture of the pelvis, or a bullet wound of pelvis, buttock, or thigh, a catheter should be passed into the bladder. If the urethra is ruptured the catheter may pass well up into the pelvis, but it will not draw urine, and if there is any doubt as to injuries about the perineum the extravesical course of the catheter may be readily identified by palpating it with the finger introduced into the rectum.

A slight injury to the prostatic urethra may produce only a hemorrhage into the bladder, which may be overlooked, may result in infiltration of urine, or may leave a urinary fistula.

Shock and the associated injuries to viscera, vessels, and bone constitute the immediate dangers; but if the passage of a catheter reveals rupture of the urethra, provision must be made by perineal or suprapubic section for drainage of the bladder, unless this is assured by the character of the wound. Lacking this, the patient will probably die of urinary infiltration.

The ultimate prognosis as to restoration of the urinary function and the occurrence and extent of traumatic stricture depends upon the nature of the injury and the thoroughness of treatment.

The diagnosis is made by passage of a catheter. The shock and the wound are treated in the usual manner.

If the catheter will not pass, the bladder is to be drained by suprapubic or perineal section, a tube being left in the wound for drainage.

No immediate attempt at restoration of the urethra is warrantable, beyond attaching the two ends of the natural roof to each other and to the surrounding fascia, if this is possible. The perineal wound should always be left widely open, and if there is a perineal hematoma this should be opened by a median incision and the clots evacuated, even though the bladder is drained suprapubically.

Immediate closure of a rectal tear may, however, be successful and this should always be attempted, using fine chromic catgut and protecting the suture line as well as possible by suturing the levator and across it. The propriety of immediate colostomy may be considered.

After infection has been controlled and the complete diagnosis made by radiograph, and if necessary, by cystography the urethral wound is attacked according to the following principles:

1. An uncomplicated complete division of the posterior urethra may sometimes be healed by suprapubic cystotomy followed by suture of the urethra over a catheter, any defects in the urethral channel being pieced out by transplanted flaps of skin or mucous membrane. If the loss of tissue in the perineum is great this had better be filled in by a skin flap swung over from an adjoining portion of the thigh. Otherwise the dense perineal scar will obliterate the urethra.

2. If there is considerable loss of tissue, after suprapubic drainage has been established, a graft of skin or mucous membrane is sutured in place between the divided ends so as to form the roof of the urethra. The wound is then packed and after a slow healing and probably one or two accessory plastic operations the urethra lumen may be reestablished.

3. If complicated by a wound of the rectum a preliminary colostomy should be done rather early. This alone may be sufficient to cause healing of the wound in the bowel, or it may be necessary to freshen the cut edges and suture them or even bring the bowel down to form a new anus. Not until the rectal wound has been closed should any attempts be made to close the urethra. Thereafter the colostomy wound may be closed.

4. Wounds of the prostatic urethra have usually been associated with so great a loss of tissue as to defy closure by operation.

WOUNDS OF THE BULBOUS URETHRA

Wounds of the bulbous urethra like those of the posterior urethra, are usually but a part of grave injuries of the adjoining structures. The chief interest attached to them relates to the various plastic operations which may be performed for the restoration of the urethra in the perineum.

CASE RECORDS

In detailing his experiences in France with wounds of the genitourinary tract, as consulting surgeon to a base center, Stevens[5] cites the following interesting case:

Case 25. Machine-gun bullet wound, the entrance being in the left buttock and the exit in the right wall of the scrotum. The patient had not tried to urinate. Nevertheless, it seemed extraordinary that no swelling, induration, or ecchymosis was present in the perineum.

The urethral lesion was diagnosed by the patient's inability to urinate and the physician's inability to pass a catheter. In its course the bullet had completely divided the bulbous urethra, and perforated an old right-sided hernia; this explained the presence of a mass of omentum protruding from the scrotal wall. The cord and testicle were uninjured. Operation was performed eight hours after the wound was received. The injured omentum was excised and the hernia repaired. Then, through a perineal incision, an end-to-end suture of the urethra was done, and perneial drainage established proximal to the suture line. The subsequent course was entirely satisfactory up to the fifth day, when the patient was evacuated to the base.

Case 26. P. H. G., private, 23d Infantry. Wounded June 14, 1918, at 2 p. m. Shell fragment entered posterior aspect of right thigh, passed just posterior to femur, exit wound being on the inner aspect of the thigh close to the perineum. Projectile then entered perineum, severed the urethra close to the bulb, divided the left spermatic cord, and tore its way out through the abdominal wall in the left inguinal region without entering the peritoneal cavity. Operation 10 p. m., same date. Débridement of the thigh wound, left castration, and suprapubic cystostomy. Evacuated June 22, to Base Hospital No. 18, where, on June 23, examination revealed a large sloughing wound of hypergastric region involving the recti muscles; suprapubic drainage wound; wound of thigh; incisions in left groin, scrotum, and dorsal surface of penis. Dakin's solution applied continuously with frequent dressings. June 28, wounds were cleaner and condition better, but suddenly patient began to have clonic spasms, slight strismus present, and his reflexes were hyperactive. Diagnosis: Tetanus. Antitetanic serum, 20,000 units administered; general condition, worse the next day. A lumbar puncture withdrew fluid under tension. Patient received antitetanic serum 10,000 units subcutaneously each day. On July 3 a second lumbar puncture was done and 20,000 units given intraspinally. Steady improvement now began. July 6, external urethrotomy, suprapubic tube removed. The good effect of dependent drainage afforded by external urethrotomy was soon demonstrated in the condition of all the wounds. Several large sloughings separated from the suprapubic wound and the thigh wound filled in rapidly. Owing to the fact that this hospital was functioning as an evacuation hospital it was necessary to evacuate on account of the exigencies of the service. Again seen June, 1919. General condition excellent, all wounds healed, perfect urinary control, urine passed entirely through perineal fistula.

Case 27. W. B., sergeant, 30th Infantry. Wounded by a rifle bullet, June 20, 1918. The missile entered left side of scrotum, severing urethra at peno-scrotal junction, entering inner aspect of left thigh and making its exit at gluteal fold of left thigh. Patient reached Field Hospital No. 27, where a paralysis of the left leg, retention of urine, and inability to pass catheter were noted. Suprapubic cystotomy was done and patient evacuated. At Evacuation Hospital No. 7 it was impossible to introduce a catheter (either anterior or retrograde). Admitted to Base Hospital No. 18 June 23, where thigh wounds were opened and pus evacuated—Dakin's solution. Found impossible to pass catheter. July 8, external urethrotomy and operative attempt made to approximate torn ends of the urethra. Tube was placed in bladder through perineal wound and suprapubic tube removed. July 13, catheter was passed through meatus up into the perineal wound where it was introduced into the bladder; perineal wound closed over it; small protective drain to take care of any leakage. July 20, catheter withdrawn but subsequently had to be reintroduced. August 10, necessary to evacuate the patient; all wounds granulating well, patient voiding, at normal intervals, clear uninfected urine, No. 24 F sound could be introduced into the bladder through small perineal fistula present but rapidly closing.

Case 28. E. G., private, 39th Infantry. Wounded August 5, 1918, by machine-gun missile which passed through left leg, upper inner portion of right thigh into perineum, severing membranous urethra and causing fracture of ischium and extravasation of urine. Operation, Field Hospital No. 19, wounds débrided, external urethrotomy with plastic reconstruction of the urethra, suprapubic cystotomy done. August 9, admitted to Base Hospital No. 18; bladder was draining well through suprapubic and perineal tubes; suture wound of perineum badly infected; three stitches removed, pus evacuated. All wounds treated by continuous Dakin's solution. August 14, all wounds cleaner. Suprapubic tube

had been removed and all urine was passed by perineal tube. It was planned to treat this case like the preceding one, but in order to prepare for fresh convoys of casualties it was necessary to evacuate patient. This case illustrates the inadvisability of attempting any plastic procedure for the repair of the urethra at the first operation; resulting scar will seriously hamper future operative procedure for repair of urethra.

The following case report has been taken from clinical records of members of the American Expeditionary Forces.[3]

Case 29. R. F. S., 105796, Company D, 2d Machine-Gun Battalion. Wounded July 18, 1918. Gunshot wound, entrance right buttock, exit left pubis, perforation of urethra and fracture of pubis. No record of operation, which was done in a French military hospital. Complications: Traumatic stricture of urethra and three urinary inguinal fistulæ. August 14, 1918, operation, A. R. C., Military Hospital No. 1. Incision from wound in left groin to perineum. Fracture of superior ramus of pubis discovered. Evacuation of large abscess cavity beneath pubis extending to prostatic region of bladder. Urethra found completely severed in front of prostate. Catheters were inserted through penis into bladder and out suprapubic wound; bladder irrigation; Carrel tubes for other wounds. January 1, 1919, impassable stricture. Perineal urethrotomy; stricture divided; suprapubic opening enlarged and opening into bladder through sphincter determined; rubber tube passed through perineal wound into bladder and suprapubic wound closed. January 30, 1919, secondary hemorrhage, packing of perineal wound. September 27, 1919, demobilized, 30 per cent disability, on account of traumatic stricture of urethra, maximum improvement attained.

FISTULA OF THE URETHRA

Urethroperineal fistulæ are usually irregular and embedded in dense scar. They may heal even after remaining open for months. If healing is despaired of, they may be closed by a plastic operation; but before this is attempted several specimens of tissue, excised from the region of the orifice of the fistula should be stained and examined for tuberculosis, as a persistent perineal fistula is often due to this disease. If acid-fast bacilli are found, the treatment should be conservative, consisting of a thorough curettage of the fistulous tract with excision of all pockets and followed by cauterization of the wound down to its urethra orifice. This operation produces surprisingly good results both in reducing the size and complications of the stricture and in some cases even closing it.

In the absence of tuberculosis the following operation should be performed: A sound should be introduced into the urethra and the whole of the perineal scar excised, the strictured urethra being dealt with according to the requirements of the case. Drainage is procured by a small tube introduced into the bladder through the suprapubic opening. The perineal urethra is then closed by fine chromic gut sutures, the perineal muscles carried over this line of suture and ample drainage left in the superficial tissues.

FISTULA OF THE PENILE URETHRA

A fistula of the penile urethra, if small, may be encouraged to heal by touching lightly with the actual cautery.

If the loss of tissue is considerable the urethra may best be closed by the following operation: 1. Drainage of the bladder by suprapubic tube. 2. The skin or scar about the fistulous orifice is divided at a point far enough away from this orifice to permit a flap to be lifted and turned in, so that the skin

surface will form the floor of the urethra. This incision will usually have to be made about 1 cm. from the orifice. It is convenient to keep a sound in the urethra while making it. The flaps may be rectangular or the incision may be an ovoidal one surrounding the fistulous opening. In lifting up the flap, great care should be taken not to puncture the underlying urethral mucosa and to retain a fair blood supply for the flap itself. The tissues will usually be so thin about the edges of the fistula that the flap can not be dissected up any nearer than about 0.5 cm. from its orifice. The flap edges are then turned in by one of two methods; viz. either the edges themselves are sutured together with plain catgut or else the whole cuff or flap is caught up in a purse-string suture, the ends of which are drawn into the urethra through the fistula, brought out at the external meatus and tied rather tightly over a small piece of gauze across the meatus. If the latter procedure is employed it is wise to insert a split tube of a few strands of silkworm gut through the external meatus into the urethra to provide for the exit of the secretions which accumulate in it. The superficial skin and fascia are then dissected free in a lateral direction half way around the penis on each side and brought together by mattress sutures of heavy catgut.

URETHRORECTAL FISTULA

This condition results frequently from wounds by missiles, or from abscesses involving the prostate and posterior urethra.

The escape of urine into the rectum and of gas and feces into the urethra lead to great discomfort. As a rule the condition is not associated with incontinence of urine, but if the internal sphincter has been injured urine may flow constantly from the bladder into the rectum, and if the external sphincter is impaired incontinence of urine and frequent escape of gas and liquid feces through the penile urethra may occur.

Not infrequently a previous perineal operation upon the prostate, or the incision of a prostatic abscess through the rectum, may be responsible for the rectourethral fistula.

TREATMENT

When it is discovered that the wound involves both the rectum and urethra, its spontaneous closure should be encouraged by providing suprapubic drainage to divert the flow of urine, and by dilating the sphincter ani widely to facilitate the passage of feces.

No attempt at primary closure of the rectal and urethral openings should be made unless, in the removal of the missle, the rectal opening is small and the wound conditions are such as to justify attempt at primary closure.

During the convalescence examination for urethral stricture should be made, and if present it should be dilated with filiforms, followers, and sounds, controlled by finger in rectum.

In many cases, especially where suprapubic drainage has been maintained, spontaneous closure of the fistula occurs, but where this does not occur, after many weeks, operation should usually be undertaken.

OPERATION TO CLOSE FISTULA

The many procedures which have been advocated attest to the great difficulty which has been encountered in curing urethrorectal fistulæ. A method which has shown almost invariable success is as follows:[7]

First, suprapubic drainage of the bladder is established, with the patient in dorsal posture. The patient is then shifted to the exaggerated lithotomy position. A racquet-shaped incision, beginning in the mid-line of the perineum about 3 cm. anterior to the anal margin, is carried backward to this margin, and then encircles it at the mucocutaneous junction. Through the circular part of this incision the mucosa of the rectum is dissected free all round until a cylinder of the membrane is stripped from its attachments well above the point at which the rectal orifice of the fistula opens, the fistulous tract being divided transversely in this process. This dissection of the bowel is carried upward until sufficient mucous membrane is loosened to permit the pulling of the segment containing the fistulous orifice well out of the anus. The orifice and a small margin of normal mucosa above it, and all that below it, lying outside of the skin level are excised later. This procedure may be described as an exaggeration of the Whitehead principle in operating for hemorrhoids. The Young long urethral tractor is often very useful in drawing down the prostate and in facilitating the separation of rectum and prostate.

A minor point of some practical importance consists in beginning the dissection of the mucosa at the posterior or dorsal part of the circle. By so doing, not only is it easier to find normal planes of cleavage here, where there is no scarring but also the field is rendered less obscure by hemorrhage than would be the case if the anterior side be first attacked, as blood then runs down over the posterior half of the anus.

The structures of the perineal body are next divided through the straight incision in the midline (the handle of the racquet) so as to expose thoroughly the urethral orifice of the fistula. If the sphincter ani previously has been cut, the ends should be dissected free from scar tissue. In many cases the sphincter ani may be left intact, being pulled out of the way with a retractor as required. In some cases it may be advisable to divide it. The edges of the urethral fistulous opening then exposed are freshened and brought together with catgut sutures over a sound which has been previously passed through the urethra. These sutures do not penetrate the surface of the urethral mucous membrane. The levators, fascia, and smaller muscles are then brought together by interrupted catgut sutures across the midline of the perineum in several layers, reconstructing the perineal body much as is done in gynecological operations for relaxed vaginal outlet. Finally, the sphincter ani, if it has been cut, is restored by uniting its ends with a mattress suture of catgut, and the midline incision is closed with interrupted sutures. The last stage in the operation consists in the excision of the protruding cuff of rectal mucosa in which the fistulous opening lies, and the union of the lower end of the rectum to the anal skin margin. This is done by interrupted silk sutures after four submucous-subcutaneous sutures of catgut have been placed at quadrant points to help anchor the bowel in place.

It will be seen that there are four essential principles in this procedure. The first is the protection of the repair from leakage and muscle spasm by diverting urine from the urethra through suprapubic drainage. The second principle is the complete ablation of the damaged portion of rectal wall and the reposition of perfectly sound mucosa quite to the skin edge. The third element in the operation is the closure of the urethral orifice; and the final essential is the interposition between rectum and urethra of a solidly built up perineal body.

WOUNDS OF THE EXTERNAL GENITALIA

Gunshot wounds of the external genitalia occurred in the American Expeditionary Forces as follows:[2] Penis, 171; scrotum, 499; testicle, 237.

In a series of 42 cases of injury to the penis, involving the penile urethra or the penis alone, rifle and machine-gun missiles were the cause of 27; shrapnel and high-explosive shell, 14; indirect injury, 1. The entrance wound involved the penis in 29 instances; the thigh in 9; buttock, 1; hip, 1; abdomen, 1. Secondary injuries numbered 20.

In a series of 164 cases of injury to the scrotum and testicles,[3] 95 of the wounds were due to rifle or machine-gun missiles; 58 to shrapnel and high-explosive shells; 5 to grenade fragments; 2 to revolver missiles. In 83 cases of scrotal injury the testicles were not involved, or at least not sufficiently involved to require operative treatment. There were 81 cases in which injury to the testicles was recorded, necessitating a right orchidectomy in 31 instances, a left orchidectomy 23 times, and a bilateral orchidectomy twice. Among the 81 cases with testicular injury, there were 10 deaths, but among the 83 cases in which the scrotum was involved, 5 deaths occurred.

WOUNDS OF THE SCROTUM, TESTICLES, PENIS, AND ANTERIOR URETHRA

Gunshot wounds of the external genitals often involve both scrotum and penis, producing extensive laceration. The primary indications are the following: (1) Control hemorrhage. (2) Carefully excise all contused tissue so as to forestall infection. (3) Do not remove a testicle unless its blood supply is irreparably damaged. Even if the tunica albuginea is split open the wound edges may be freshened and sutured with chromic catgut. (4) No attempt should be made at this time to replace the testicle in the scrotum. (5) A catheter should be tied into the urethra, both to prevent cicatrical contraction of its orifice and to insure the patient against retention of urine. If the urethra is completely divided this catheter will issue from the wound and a second section of catheter should be inserted into the anterior portion of the urethra so as to prevent cicatricial contraction of its cut end. (6) The penile wound should be dressed wide open. If the penis is partially divided, even though the slip of tissue by which it adheres is insignificant, every effort should be made to preserve the end of the organ while dressing the wound wide open and awaiting the opportunity for secondary plastic operation.

RUPTURE AND TRAUMATIC STRICTURE OF THE URETHRA

Traumatic stricture following wound or rupture of the urethra has the following characteristics: (1) The gravest type of stricture may result from an injury so slight as to cause but little hematuria and no important disturbance of urination. (2) Traumatic stricture usually appears, and recurs after operation, with great rapidity. Stricture resulting from even the slightest injuries may contract so rapidly as to cause complete retention of urine within a few weeks, and, following simple external urethrotomy without resection of the urethra, such a stricture may recur and cause retention before the patient leaves the hospital. (3) Traumatic stricture is usually extremely resistant, rebellious to treatment by sounds and, as stated above, to the simple forms of operation.

PROPHYLACTIC TREATMENT

The most important feature in the treatment of traumatic stricture is its prophylaxis. Wounds of the urethra that do not completely sever the canal are not likely to result in severe strictures, but all wounds severing the canal and all contusions or ruptures of the urethra, be they ever so slight, should be regarded with grave apprehension and serious efforts made to prevent the formation of residual traumatic strictures, as follows: The indwelling catheter should not be employed, since it only encourages infiltration and scar formation in the wound. Stricture of the prostatic urethra may be prevented by the bladder drainage which the wound itself required. Rupture of the membranous urethra (usually caused by the so-called straddle injury) calls for immediate perineal section and drainage with a large tube for three or four days in order to establish the lumen of the urethra and prevent infiltration of urine and subsequent stricture. This rule applies even to those cases whose only symptom is a slight urethral hemorrhage. Perineal section is likewise required to prevent stricture of the bulbous urethra. No special measures need be taken to prevent stricture following injuries to the pendulous urethra, excepting the use of the indwelling catheter in order to keep the cut ends from contracting during the first week after injury, and the frequent passage of sounds after reconstruction of the canal. Stricture will surely ensue, but it is readily controllable.

OPERATIVE TREATMENT

Stricture of the prostatic urethra usually occurs at the bladder neck and may be cured by the use of Young's prostatic punch. If the stricture is so tight as not to admit this instrument, it may be attached by the suprapubic route, the pin-point urethral opening being first divulsed and then the whole floor of the urethra at the bladder neck being removed by rongeur forceps, scalpel, or scissors.

Traumatic stricture of the bulbous or membranous urethra requires excision. Through a median or curved incision the perineal urethra is laid bare, and the precise location of the stricture identified by the passage of urethral instruments. The stricture is then divided longitudinally and one of three procedures follows:

(*a*) If the scar is relatively narrow, especially upon the roof of the canal, the urethra is resected by Cator's method. The bulbous portion of the canal is freed for at least 3 cm. from its attachment to the corpora cavernosa. The scar tissue is split open on the floor of the urethra in the direction of the long axis of this canal and any dense masses of scar tissue are excised. A small sound is placed in the urethra as a guide and the gap in the urethral wall is closed about this by fine transverse chromic catgut sutures, beginning at the lateral angles of the wound and inserted alternately on each side, finishing at the median line. None of these sutures is tied until the last one has been inserted. Then a small puncture is made, upon a staff, in the urethra behind the suture line, and through this an 18 F soft rubber catheter is introduced into the bladder for drainage. The sound is then reintroduced and the sutures tied in the same order as they were imserted. The mobilized urethra is thus drawn down into the perineum and the urethral wound tightly closed. The bulbocavernosus muscle is now drawn across the line of suture and the dislocated bulbous urethra by a few catgut sutures, the anterior end of the skin wound closed, but a wide opening left in the superficial tissues about the catheter in the perineum, so as to prevent infiltration. The catheter is retained for 10 days. (*b*) If resection of the roof of the urethra is required, a transverse section of the urethra is excised, suprapubic drainage established, the cut edges of the urethra drawn together by a few fine chromic gut sutures, and the urethral stumps carefully supported by three or four heavier chromic sutures so as to take the strain off the cut edges. The deep tissues of the perineum are fully closed, but the superficial tissues are drained. (*c*) If the gap is so wide that no reconstruction is possible, the scar is excised and the two cut ends of the urethra brought out into the perineum for subsequent reconstruction of the urethra.

Traumatic strictures of the pendulous urethra are controllable by internal urethrotomy. The rapidity with which the stricture contracts makes the Maisoneuve urethrotome the instrument of choice.

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(2) Based on sick and wounded reports to the Surgeon General.
(3) Clinical records, American Expeditionary Forces. On file, A. G. O., World War Division, Medical Records Section.
(4) Surgical reports made to the chief consultant, surgical services, A. E. F. On file, Historical Division, S. G. O.
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CHAPTER XVII

END RESULTS, FRACTURES OF LONG BONES

Before entering into the consideration of the end results of the fractures of the long bones that occurred during the World War, it is necessary to give the numbers of fractures involving not only the long bones but others as well, in order that their relative incidence and gravity may be more readily appreciated. This will be done for both battle and nonbattle fractures.

TABLE 28.—*Battle fractures, including single and associated fractures* [a]

Location	Number
Lower extremity:	
Femur	3,850
Fibula	2,697
Tibia	4,379
Greater trochanter	76
Malleolus	327
Patella	452
Acetabulum	15
Tarsus	1,082
Metatarsus	2,273
Ankle	12
Hip	10
Knee	19
Leg	62
Total	14,254
Trunk:	
Ilium	432
Ischium	84
Pubis	61
Sacrum	100
Coccyx	16
Vertebræ	378
Ribs	729
Sternum	23
Total	1,733
Face:	
Malar	64
Maxilla—	
Inferior	1,123
Superior	323
Nasal	77
Vomer	20
Zygoma	29
Total	1,636
Upper extremity:	
Humerus	4,069
Radius	2,475
Ulna	2,150
Clavicle	497
Olecranon	240
Carpus	336
Metacarpus	1,851
Scapula	806
Elbow	13
Forearm	25
Shoulder	10
Wrist	15
Total	12,487
Head:	
Frontal	375
Mastoid	67
Occipital	251
Parietal	408
Skull base	326
Skull vault	360
Temporal	244
Total	2,131
Grand total	32,331

[a] Source of information: Sick and wounded reports made to the Surgeon General

It is seen from the above table that there were 19,620 fractures of the extremities, as follows:

Femur	3,850
Fibula	2,697
Humerus	4,069
Radius	2,475
Tibia	4,379
Ulna	2,150
	19,620

Arranging the figures from the standpoint of the individual, and so as to show not only the single fractures but also those that were associated, we arrive at the result given in Table 29. This table gives the true situation, particularly with respect to mortality.

TABLE 29.—*Battle fractures, long bones, showing both single fractures and those in association, and deaths* [a]

Location	Number	Deaths
Femur:		
alone	3,296	804
and fibula	46	16
and humerus	194	68
and radius	73	17
and tibia	177	58
and ulna	64	8
Total femur	3,850	971
Fibula:		
alone	1,013	55
and humerus	27	5
and radius	3	2
and tibia	1,600	278
and ulna	8	0
Total fibula	2,651	340
Humerus:		
alone	3,549	304
and radius	132	10
Humerus—Continued.		
and tibia	83	20
and ulna	84	7
Total humerus	3,848	341
Radius:		
alone	1,492	48
and tibia	33	7
and ulna	742	34
Total radius	2,267	89
Tibia:		
alone	2,471	251
and ulna	15	1
Total tibia	2,486	252
Ulna	1,237	26
Total	16,339	2,019

[a] Source of information: Sick and wounded reports made to the Surgeon General.

In addition to the fractures incident to battle, there were 39,569 fractures, the result of nonbattle injury. Of these, 31,776 were simple fractures, with a mortality of 664, or 2.09 per cent, and 6,006 were compound, with a mortality of 663, or 11.04 per cent. With the view of showing the relative frequency during the World War of nonbattle fractures of not only the separate long bones, but also of all the bones reported to have been fractured, the following table has been prepared:

TABLE 30.—*Nonbattle fractures* [a]

Location	Simple		Compound		Location	Simple		Compound	
	Number	Deaths	Number	Deaths		Number	Deaths	Number	Deaths
Head	961	366	599	373	Femur	773	27	318	62
Face	2,218	14	577	15	Greater tuberosity	16	0	1	0
Vertebræ	182	50	17	12	Lesser tuberosity	1	0	0	0
Ribs and sternum	1,683	22	33	5	Patella	346	0	56	2
Clavicle and scapula	1,823	4	54	0	Fibula	3,309	8	357	18
Humerus	1,024	2	218	11	Tibia	2,627	8	754	32
Ulna	980	1	112	1	Knee	17	0	2	0
Elbow	20	0	1	0	Tibia and fibula	31	2	13	2
Olecranon	231	0	31	1	Ankle	65	1	2	0
Radius	4,432	7	237	8	Malleolus	1,149	5	51	2
Radius and ulna	23	0	5	0	Tarsus	569	2	124	1
Wrist	51	1	0	0	Metatarsus	1,144	2	379	1
Carpus	505	0	35	1	Foot	15	0	6	0
Metacarpus	2,122	1	334	2	Toe	672	0	317	0
Hand	25	0	9	0	Miscellaneous	3,214	104	506	103
Fingers	1,309	1	835	3					
Pelvis	233	16	23	8	Total	31,776	644	6,006	663
Hip	6	0	0	0					

[a] Source of information: Sick and wounded reports made to the Surgeon General.

Table 31 shows the result, in so far as death and recovery are concerned, in the cases of both battle and nonbattle fractures, and while the men involved were in the military service.

TABLE 31.—*Battle and nonbattle fractures of long bones, showing immediate result*

Location	Number of cases			Deaths			Recovery		
	Battle	Non-battle	Total	Battle	Non-battle	Total	Battle	Non-battle	Total
Femur:									
alone	3,296	1,091	4,387	804	89	893	2,492	1,002	3,494
and fibula	46	0	46	16	0	16	30	0	30
and humerus	194	0	194	68	0	68	126	0	126
and radius	73	0	73	17	0	17	56	0	56
and tibia	177	0	177	58	0	58	119	0	119
and ulna	64	0	64	8	0	8	56	0	56
Total femur	3,850	1,091	4,941	971	89	1,060	2,879	1,002	3,881
Fibula:									
alone	1,013	3,666	4,679	55	26	81	958	3,640	4,598
and humerus	27	0	27	5	0	5	22	0	22
and radius	3	0	3	2	0	2	1	0	1
and tibia	1,600	44	1,644	278	4	282	1,322	40	1,362
and ulna	8	0	8	0	0	0	8	0	8
Total fibula	2,651	3,710	6,361	340	30	370	2,311	3,680	5,991
Humerus:									
alone	3,549	1 242	4,791	304	13	317	3,245	1,229	4,474
and radius	132	0	132	10	0	10	122	0	122
and tibia	83	0	83	20	0	20	63	0	63
and ulna	84	0	84	7	0	7	77	0	77
Total humerus	3,848	1,242	5,090	341	13	354	3,507	1,229	4,736
Radius:									
alone	1,492	4,669	6,161	48	15	63	1,444	4,654	6,098
and tibia	33	0	33	7	0	7	26	0	26
and ulna	742	28	770	34	0	34	708	28	736
Total radius	2,267	4,697	6,964	89	15	104	2,178	4,682	6,860
Tibia:									
alone	2,471	3,381	5,852	251	40	291	2,220	3,341	5,561
and ulna	15	0	15	1	0	1	14	0	14
Total tibia	2,486	3,381	5,867	252	40	292	2,234	3,341	5,575
Ulna	1,237	1,092	2,329	26	2	28	1,211	1,090	2,301
Elbow	0	21	21	0	0	0	0	21	21
Knee	0	19	19	0	0	0	0	19	19
Ankle	0	63	63	0	1	1	0	62	62
Wrist	0	51	51	0	1	1	0	50	50
Total	16,339	15,367	31,706	2,019	191	2,210	14,320	15,176	29,496

To determine the end results among as great a number as possible of the recovered (from the Army viewpoint) fracture cases shown in Table 31, a statistical study has been made of such of these men as applied for compensation to the Bureau of War Risk, or subsequently, the United States Veterans' Bureau, which replaced the Bureau of War Risk.[1] This study, which was begun in December, 1919, by the Surgeon General, United States Public Health Service, acting for the Bureau of War Risk under the Treasury Department, was completed by the United States Veterans' Bureau.[1] It extended over a six-year period, ending January 1, 1926, and shows the progress and end results of the cases in question.

From the first, the importance of an individual study of the fractures of the long bones among veterans of the World War was recognized, so the use of a specially designed form was authorized to report the desired information whenever the condition was revealed at the time of physical examination of veterans applying for compensation. This form is as follows:

VETERANS BUREAU,
MEDICAL DIVISION.
Form 2540.

REPORT ON FRACTURES—LONG BONES

Army Serial No. ------------ Claim No. ----------------

Name -- Age ---- Rank ------ Co. ---- Organ. ---------- Army—Navy.

Permanent Address --

Date of Discharge ---------------------- Date of Injury ---------------------- Date of Report ------------------------------

Bone, Name of ---------------------- R.—L.—Head—Neck—Up.—Mid.—Low.—Third—Int.—Ext.—Cond.—Mall.—Involv.—Joint.

Form of fracture: Simple—Compound—Comminuted. Wound: Soft parts healed: Yes—No.

Union: Firm—Faulty—None. Bone Graft: Yes—No. Bone Plate: Yes—No. Date inserted -------------- Date removed -----------

Osteomyelitis: Yes—No. Healed: Yes—No. Deformity: Bowing—Ant.—Post.—Outward—Inward.

Nerve involvement: Yes—No—Which -------------- Shortening: Inches------------------------------

Atrophy: Yes—No. Extensive loss of muscle: Yes—No. Functions of joints: Free—None—Limited. Degrees of limitation----

Wrist-drop: Yes—No. Foot-drop: Yes—No. Ankylosis: Fibrous—Bony. Angle: Favorable—Unfavorable.

Using crutch? ---------- Brace? ---------- Cane? ---------- (Shoulder—Wrist—Elbow—Hip—Knee—Ankle.)

Occupation before the war -- Will he be fully able to do his former work? Yes—No.

What occupation is he best suited for?------------------------------ REMARKS: ------------------------------

Is he mentally and physically capable of being trained therefor? Yes—No. ------------------------------------

Date of last X ray -- --

Disability— Permanent— Temporary— Partial— Total— --

District reporting -- Examiner reporting ------------------------------

INSTRUCTIONS.—Draw a line through terms not applicable. One card to be made for each bone injury. Card to be attached to Report of Physical Examination and forwarded to Medical Adviser, Veterans' Bureau, Washington, D. C., through the District Supervisor.

Since, in the tables which follow, the compensation rating is the index of the disability, it is necessary to know what the schedule of ratings comprises, in order properly to understand the tables. The following ratings, in force in the United States Veterans' Bureau, is the outcome not only of experience in the bureau but also of expressed opinions of various leading surgeons in the United States; in addition, the schedule of ratings of England, France, Belgium, and Canada were taken into consideration in its adoption.

RATINGS OF AMPUTATIONS, FRACTURES, AND THEIR SEQUELÆ

In general, loss of muscle substance, cicatrices, and atrophies, when having an effect upon functions, from 10 per cent to 25 per cent should be added to the specific rating.

Shoulder

	Per cent
Bony ankylosis:	
Major—	
Favorable angle	36
Unfavorable angle	45
Minor—	
Favorable angle	28
Unfavorable angle	36
Limitation of motion from full flexion to 90°, same as ankylosis.	
Inability to raise arm above 90°	30

Elbow

Complete bony ankylosis:	
Major—	
Favorable angle	35
Unfavorable angle	50
Minor—	
Favorable angle	30
Unfavorable angle	45
Limitation of flexion of the forearm from—	
160°–110°—	
Major	25
Minor	20
160°–90°—	
Major	20
Minor	15
180°–70°—	
Major	5
Minor	5
Loss of extension of the forearm from—	
60°–180°—	
Major	50
Minor	40
75°–180°—	
Major	45
Minor	38
90°–180°—	
Major	25
Minor	20
105°–180°—	
Major	20
Minor	15

Loss of extension of the forearm from—Continued.

	Per cent
120°–180°—	
Major	15
Minor	10
135°–180°—	
Major	10
Minor	10
150°–180°—	
Major	5
Minor	5

(Extension from a position of complete flexion to the arc specified is unrestricted but wholly lost through the arc specified.)

Hip

Bony ankylosis:

Favorable angle	36
Unfavorable angle	45

Limitation of motion, from 5 per cent to 35 per cent, depending upon degree.

Knee

Complete bony ankylosis:

Favorable angle	35
Unfavorable angle	50

Limitation of flexion of the leg from—

180° to 105°	5
180° to 120°	10
180° to 135°	15
180° to 150°	20
180° to 165°	30

(Flexion is unrestricted through the arc specified, but wholly lost beyond the arc specified.)

180° (complete ankylosis)	35

Loss of extension of the leg from—

90°	
105° to 180° (the equivalent of an amputation of the thigh through the lower third)	58
120°	
135°	
150° to 180°	40
165° to 180°	20
170° to 180°	10
175° to 180°	5

(Extension from a position of complete flexion is unrestricted excepting through the arc specified.)

The axis of 180° corresponds to the axis of the proximal long bone on which the distal long bone moves in the arc of a circle. Extreme flexion of the forearm is approximately at an angle of 45°. Extreme flexion of the leg is approximately at an angle of 75°. Complete extension of either forearm or leg is at 180°.

Where a partial disability results from an injury to both members, involving bilateral function, 20 per cent of the total rating, provided by the present schedule for the partial loss of bilateral function, will be added to the sum of the ratings for impaired function in both members.

Nonunion of bones:

Rating to be equivalent to temporary partial rating for amputation at site of nonunion, except ulna, which is to be rated 10 per cent.

Faulty unions rate on percentage of loss of function comparable to limitation of motion of contiguous joints.

Subluxations comparable to ankylosis at favorable angle.

Acute osteomyelitis, acute bursitis, acute synovitis, acute tenosynovitis, rate temporary total.

Chronic "ditto," rate on sequelæ.

Persistent dislocations, rate 25 per cent less than loss of limb at joint affected.

Loss of pronation and supination rate 15 per cent.

Amputations

ARM	
Disarticulation:	
Major	94
Minor	85
Upper and middle third:	
Major	89
Minor	80
Lower third:	
Major	84
Minor	75
FOREARM	
Upper third:	
Major	75
Minor	63
Lower third:	
Major	70
Minor	58
THIGH	
Disarticulation	80
Upper third	80
Middle third	63
Lower third	58
LEG	
Upper third	49
Lower two-thirds	44
Tarso-metatarsal joint	30
Shortening of leg (permanent partial):	
1 inch	10
1½ to 2 inches	20
2½ to 3½ inches	45
4 to 5 inches	60

The subjoined statistical tables comprise three groups. The first group, Tables 32 to 39, gives general information concerning the men who suffered a fracture of one or more long bones; the second and third groups cover changes in degree of impairment, from the date of injury to January 1, 1926.

Table 32 shows the bones involved, as well as the deaths. In this and subsequent tables, figures for veterans of both the Navy and the Marines have been included, since, in the United States Veterans' Bureau no distinction is made between these services and the Army. The number of cases that originated in the Navy is 859; in the Marines, 562. Of the total number of cases in Table 32, 4,519, or 19.69 per cent, had simple fractures; 18,435, or 80.31 per cent, had compound fractures. It is noteworthy that in the column for fractures involving either the tibia or the tibia and fibula, the 6,620 cases include all fractures of the tibia and also all cases of major fracture involving the tibia and fibula. This remark is equally true of the column for the radius or radius and ulna.

Table 33 shows that 69.05 per cent of the injured veterans were under 30 years of age. The fact that there was such a large number of these men under the age of 30 increased the possible economic benefits from rehabilitation.

The large number of serious complications, infections, and associated conditions, shown in Table 34, reveal the severity of the fractures.

Table 35 shows that it has been possible to place 15,597 of the claimants, or 67.95 per cent, with disability due to fractures of the long bones, on a permanent rating. It is necessary to explain here that a permanent rating is not awarded until it is indicated that the disability has reached a stationary level and is reasonably certain to continue throughout the remainder of the claimant's life. Most of the 433 cases on a "temporary total" basis are under hospital treatment.

TABLE 32.—*Fractures of long bones of United States veterans of the World War, by type of fracture, showing bone or bones involved, and deaths, as of January 1, 1926* [a]

	Bone or bones involved																			
	Femur										Tibia or tibia and fibula									
	Alone [b]	Double femur	Tibia	Fibula	Tibula and fibula	Humerus	Radius	Ulna	Radius and ulna	Total	Alone [c]	Double tibia	Femur	Fibula	Tibia and fibula	Humerus	Radius	Ulna	Radius and ulna	Total
Type of fracture:																				
Simple	628	14	17	7	38	9	10	4	11	738	1,542	6	1	2	19	4	4	6	10	1,594
Compound	3,619	60	85	20	81	50	16	15	33	3,979	4,025	30	46	8	100	13	12	21	16	4,271
Not stated	313	----	8	2	2	5	1	----	----	331	814	1	2	1	----	----	3	----	3	824
Due to disease [d]	87	2	----	----	----	1	----	----	----	90	75	----	2	----	8	----	----	----	----	85
Deaths:																				
Simple	22	----	----	----	----	----	----	1	----	23	47	----	----	----	1	----	1	----	----	49
Compound	104	2	2	1	1	----	----	----	1	111	93	----	3	1	4	----	1	----	----	102
Not stated	6	----	----	----	----	----	----	----	----	6	8	----	----	----	----	----	----	----	----	8
Due to disease [d]	28	----	----	----	----	----	----	----	----	28	16	----	----	----	1	----	----	----	----	17
Total	4,807	78	112	30	122	65	27	20	45	5,306	6,620	37	54	12	133	17	21	27	29	6,950

	Bone or bones involved																			
	Fibula										Humerus									
	Alone [b]	Double fibula	Femur	Tibia	Tibia and fibula	Humerus	Radius	Ulna	Radius and ulna	Total	Alone [b]	Double humerus	Femur	Tibia	Fibula	Tibia and fibula	Radius	Ulna	Radius and ulna	Total
Type of fracture:																				
Simple	375	3	1	----	----	1	----	1	----	381	468	1	2	2	1	3	24	22	24	547
Compound	641	2	4	----	2	----	----	2	----	651	2,972	14	30	22	4	24	64	86	130	3,346
Not stated	211	----	----	----	----	----	----	----	----	211	382	----	1	2	2	2	12	12	14	427
Due to disease [d]	----	----	----	----	----	----	----	----	----	----	8	----	----	----	----	----	----	----	----	8
Deaths:																				
Simple	9	----	----	----	----	----	----	----	----	9	9	----	----	----	----	----	----	----	----	9
Compound	13	----	----	----	----	----	----	----	----	13	84	----	1	----	----	1	1	----	3	90
Not stated	2	----	----	----	----	----	----	----	----	2	6	----	----	----	----	----	----	----	----	6
Due to disease [d]	----	----	----	----	----	----	----	----	----	----	7	----	----	----	----	----	----	----	----	7
Total	1,251	5	5	----	2	1	----	3	----	1,267	3,936	15	34	26	7	30	101	120	171	4,440

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.

[b] The column captioned "Alone" indicates that there is only one long bone fractured.

[c] The major fracture may be of either the "tibia or tibia and fibula" or the "radius or radius and ulna," as is shown in the sections so marked.

[d] Fractures due to disease are cases of amputation for tuberculosis, etc. In this and the following tables amputations are included with the fractures, the amputation being due to the fracture.

TABLE 32.—*Fractures of long bones of United States veterans of the World War, by type of fracture, showing bone or bones involved, and deaths, as of January 1, 1926*—Continued

	Bone or bones involved																				
	Ulna										Radius or radius and ulna										
	Alone [b]	Double ulna	Femur	Tibia	Fibula	Tibia and fibula	Humerus	Radius	Radius and ulna	Total	Alone [c]	Double radius	Fibia	Tibia	Fibula	Tibia and fibula	Humerus	Ulna	Radius and ulna	Total	Grand total
Type of fracture:																					
Simple	201	1					1			203	907	5	1	1	4	2	5	1	18	944	4,407
Compound	758	3	7	2	6	3	8		2	789	2,095	3	21	12	5	7	19	4	21	2,187	15,223
Not stated	174						2		1	177	547	1	1			3	3		2	557	2,527
Due to disease [d]											8									8	191
Deaths:																					
Simple	1									1	21									21	112
Compound	18									18	62			1					2	65	399
Not stated	5									5	10									10	37
Due to diease [d]											5		1							6	58
Total	1,157	4	7	2	6	3	11		3	1,193	3,655	9	24	14	9	12	27	5	43	3,798	22,954

[b] The column captioned "Alone" indicates that there is only one long bone fractured.
[c] The major fracture may be of either the "tibia or tibia and fibula" or the "radius or radius and ulna," as is shown in the sections so marked.
[d] Fractures due to disease are cases of amputation for tuberculosis, etc. In this and the following tables amputations are included with the fractures, the amputation being due to the fracture.

TABLE 33.—*Fractures of long bones of United States veterans of the World War, by age group and bone or bones involved, and deaths, as of January 1, 1926* [a]

Age group	Bone or bones involved								
	Femur	Tibia	Fibula	Tibia and fibula	Humerus	Ulna	Radius	Radius and ulna	Total
Under 20	50	21	9	38	46	14	8	28	214
20–24	1,405	620	336	1,207	1,245	319	394	663	6,189
25–29	2,294	936	484	1,806	1,889	495	560	983	9,447
30–34	981	414	221	827	810	205	269	405	4,132
35–39	143	79	36	147	109	44	35	64	657
40 or over	56	46	25	74	66	16	24	34	341
Not stated	209	173	132	386	163	76	66	163	1,368
Deaths	168	50	24	126	112	24	35	67	606
Total	5,306	2,339	1,267	4,611	4,440	1,193	1,391	2,407	22,954

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.

TABLE 34.—*Fractures of long bones of United States veterans of the World War, by condition on first examination, by location of fractures, and deaths, as of January 1, 1926* [a]

Condition on first examination	Location of fracture								
	Femur	Tibia	Fibula	Tibia and fibula	Humerus	Ulna	Radius	Radius and ulna	Total
Associated conditions:									
Osteomyelitis	309	380	110	372	465	93	73	97	1,899
Osteomyelitis and shortening, osteomyelitis, shortening, and deformity	551	111	12	267	190	21	21	73	1,246
Osteomyelitis, shortening, and ankylosis	115	13	2	31	29	2	......	6	198
Osteomyelitis, shortening, deformity, and ankylosis	89	17	1	60	31	1	8	12	219
Osteomyelitis, deformity, and ankylosis	72	47	11	68	132	12	23	26	391
Shortening	689	68	16	230	160	32	27	38	1,260
Shortening and deformity	543	76	11	346	204	29	65	129	1,403
Shortening, deformity, and ankylosis	68	8	2	39	27	4	6	16	170
Shortening and ankylosis	93	11	2	27	45	3	3	8	192
Deformity	117	197	102	382	405	157	217	367	1,944
Ankylosis or ankylosis and deformity	124	80	40	157	308	49	76	143	977
Not stated	2,368	1,281	934	2,506	2,332	766	837	1,425	12,449
Deaths	168	50	24	126	112	24	35	67	606
Total	5,306	2,339	1,267	4,611	4,440	1,193	1,391	2,407	22,954
Bone graft, plating or nerve involvement:									
Nerve involvement	398	160	154	284	981	294	223	344	2,838
Bone graft with nerve involvement	8	2	1	8	21	13	20	18	91
Bone graft	46	20	2	47	20	10	22	26	193
Bone graft with nonunion	16	12	1	23	30	7	7	22	118
Bone graft with nonunion with nerve involvement	1	3	......	2	17	3	7	16	49
Nonunion with nerve involvement	11	1	9	17	67	37	22	39	203
Nonunion	58	40	23	67	98	64	23	94	467
Faulty union	171	51	17	165	100	47	50	76	677
Plating	108	7	2	34	21	......	8	13	193
Wiring	6	......	......	2	1	1	......	4	14
Not stated	4,315	1,993	1,034	3,836	2,972	693	974	1,688	17,505
Deaths	168	50	24	126	112	24	35	67	606
Total	5,306	2,339	1,267	4,611	4,440	1,193	1,391	2,407	22,954
Shortening:									
Under 1 inch	874	213	26	618	427	53	78	169	2,458
Under 2 inches	854	35	11	224	142	12	17	54	1,349
Under 3 inches	243	8	2	43	49	6	4	22	377
Under 4 inches	62	......	2	2	15	......	1	7	89
4 inches or over	16	......	1	1	4	1	......	1	24
Amount not stated	106	35	4	94	35	13	26	26	339
Not stated	2,983	1,998	1,197	3,503	3,656	1,084	1,230	2,061	17,712
Deaths	168	50	24	126	112	24	35	67	666
Total	5,306	2,339	1,267	4,611	4,440	1,193	1,391	2,407	22,954

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.

TABLE 35.—*Fractures of long bones of United States veterans of the World War, by character and degree of disability, bone or bones involved, and deaths as of January 1, 1926* [a]

Character and degree of disability	Bone or bones involved																			
	Femur										Tibia or tibia and fibula									
	Alone [b]	Double femur	Tibia	Fibula	Tibia and fibula	Humerus	Radius	Ulna	Radius and ulna	Total	Alone [c]	Double tibia	Femur	Fibula	Tibia and fibula	Humerus	Radius	Ulna	Radius and ulna	Total
Temporary partial:																				
10–19	165	1	1	1				2		170	494	4		1	2			1	1	503
20–29	127	1	5	1	4	1	3			142	278	2			4	1	1	1		287
30–39	42		1		2		1		2	48	55				2			1	1	59
40–49	24	3	3				1	1	1	33	33							1		34
50–59	44	2	3		2	1			3	55	59					1				60
60–69	20	1	1		2	1				25	13		1	1						15
70–79	18		1							19	29	2								31
80–89	4									4	2					1				3
Temporary total	173	3	5		3	1			1	186	162	3	1		4	1	2	1	2	176
Total temporary ratings	617	11	20	2	13	4	5	3	7	682	1,125	11	2	2	12	4	3	5	4	1,168
Permanent partial:																				
10–19	603	6	16	8	12	6	6	1	5	663	1,615	8		2	13	1	4	4		1,647
20–29	637	9	13	6	14	7	5	2	5	698	807	7	2	5	9	3	1	6	5	845
30–39	312	3	15	1	9	4	1	2	4	351	287	2	3	1	4		2	1	1	301
40–49	254	2	11	4	10	7	3	2	1	294	1,054		2		9	2	3	1	3	1,074
50–59	513	4	14	2	7	8	3	4	6	561	127	1	2		6	2	4	2	2	146
60–69	830	2	6	1	14	2	1	2	1	859	49	2	5		10				1	67
70–79	128	4	4	3	4	4	2		3	152	23	1	1		4		1	1	1	32
80–89	455	1	2		4	1		2	3	468	16		9		4			1	2	32
90–99	10	1				1				12			1							1
Permanent total	34	32	1	1	31	19	1	1	8	128	13	2	23		52	5			4	99
Total permanent ratings	3,776	64	82	26	105	59	22	16	36	4,186	3,991	23	48	8	111	13	15	16	19	4,244
Total rated cases	4,393	75	102	28	118	63	27	19	43	4,868	5,116	34	50	10	123	17	18	21	23	5,412
Deaths	160	2	2	1	1			1	1	168	164		3	1	6		2			176
Less than 10 per cent	254	1	8	1	3	2			1	270	1,340	3	1	1	4		1	6	6	1,362
Grand total	4,807	78	112	30	122	65	27	20	45	5,306	6,620	37	54	12	133	17	21	27	29	6,950

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] The column captioned "Alone" indicates that there is only one long bone fractured.
[c] The major fracture may be of either the "tibia or tibia and fibula" or the "radius or radius and ulna," as is shown in the sections so marked.

TABLE 35.—*Fractures of long bones of United States veterans of the World War, by character and degree of disability, bone or bones involved, and deaths as of January 1, 1926*—Contd.

Character and degree of disability	Bone or bones involved																			
	Fibula										Humerus									
	Alone [b]	Double fibula	Femur	Tibia	Tibia and fibula	Humerus	Radius	Ulna	Radius and ulna	Total	Alone [b]	Double humerus	Femur	Tibia	Fibula	Tibia and fibula	Radius	Ulna	Radius and ulna	Total
Temporary partial:																				
10–19	126	1	1							128	183	1	1			2	4	2	3	196
20–29	44	1								45	125			3		1	6	4	7	146
30–39	11									11	51					1	1	1		54
40–49	5									5	25							1	2	28
50–59	2									2	36						1	1		38
60–69											15							1	1	17
70–79											13					1		1	5	20
80–89	1									1	10									10
90–99											1									1
Temporary total	3									3	33	1	2	1		2	1	1	1	42
Total temporary ratings	192	2	1							195	492	2	3	4		7	13	12	19	552
Permanent partial:																				
10–19	329	2				1				332	709	1	3	7		3	13	21	18	775
20–29	110							1		111	563		2	3	7	3	18	22	17	635
30–39	46							1		47	327		2	4			18	15	18	384
40–49	23		1					1		25	207		2	1		2	6	16	34	268
50–59	10									10	173			1		2	12	11	20	219
60–69	5				2					7	121	2	3			1	7	4	12	150
70–79	1									1	163	1	2	3		3	5	5	11	193
80–89	2		1							3	602		1	2		2	2	1	10	620
90–99											74	1	1						2	78
Permanent total	1		1							2	4	8	13			6	1	1	5	38
Total permanent ratings	527	2	3		2	1		3		538	2,943	13	29	21	7	22	82	96	147	3,360
Total rated cases	719	4	4		2	1		3		733	3,435	15	32	25	7	29	95	108	166	3,912
Deaths	24									24	106		1			1	1		3	112
Less than 10 per cent	508	1	1							510	395		1	1			5	12	2	416
Grand total	1,251	5	5		2	1		3		1,267	3,936	15	34	26	7	30	101	120	171	4,440

[b] The column captioned "Alone" indicates that there is only one long bone fractured.

TABLE 35.—*Fractures of long bones of United States veterans of the World War, by character and degree of disability, bone or bones involved, and deaths as of January 1, 1926*—Contd.

Character and degree of disability	Bone or bones involved																				
	Ulna										Radius or radius and ulna										
	Alone [b]	Double ulna	Femur	Tibia	Fibula	Tibia and fibula	Humerus	Radius	Radius and ulna	Total	Alone [c]	Double radius	Fibia	Tibia	Fibula	Tibula and fibula	Humerus	Ulna	Radius and ulna	Total	Grand total
Temporary partial:																					
10–19	93	1								94	214				2	1	1		1	219	1, 310
20–29	41									41	102	1							2	105	766
30–39	21									21	33						1			34	227
40–49	4									4	22						1			23	127
50–59	8									8	22		1							23	186
60–69	1	1								2	6									6	65
70–79	2						1			3	12		1							13	86
80–89	2									2	2									2	22
90–99	1																				1
Temporary total	5		1							6	17		1						2	20	433
Total temporary ratings	177	2	1				1			181	430	1	3		2	1	3		5	445	3, 223
Permanent partial:																					
10–19	335	1	1	1	2		4		1	345	880	1	1			1	3	1	12	899	4, 661
20–29	182						2			184	509		1	3	1		6	1	4	525	2, 998
30–39	88				3		2			93	229	1	1	4	3	1	2		1	242	1, 418
40–49	48				1	1	1			51	143	1	1	2	1	1	3	1		153	1, 865
50–59	40			1		1				42	284	1					1		1	287	1, 265
60–69	12	1	1			1	1			16	136		1	1	1	1	3	1		144	1, 243
70–79	2		2						1	5	212	1	2	1			1		2	219	602
80–89	2		1							3	18		3	1			2			24	1, 150
90–99											3									3	94
Permanent total			1						1	2	3		9			7	3		10	32	301
Total permanent ratings	709	2	6	2	6	3	10		3	741	2, 417	5	19	12	6	11	24	4	30	2, 528	15, 597
Total rated cases	886	4	7	2	6	3	11		3	922	2, 847	6	22	12	8	12	27	4	35	2, 973	18, 820
Deaths	24									24	98		1	1					2	102	606
Less than 10 per cent	247									247	710	3	1	1	1			1	6	723	3, 528
Grand total	1, 157	4	7	2	6	3	11		3	1, 193	3, 655	9	24	14	9	12	27	5	43	3, 798	22, 954

[b] The column captioned "Alone" indicates that there is only one long bone fractured.
[c] The major fracture may be of either the "tibia or tibia and fibula" or the "radius or radius and ulna," as is shown in the section so marked.

TABLE 36.—*Fractures of long bones of United States veterans of the World War, by bone and joints involved, showing condition on first examination, as of January 1, 1926* [a]

Location of fracture	Joints with impared function							
	Hip	Knee	Ankle	Hip and knee	Knee and ankle	Not stated	Deaths	Total
Femur	361	1,432	47	165	115	3, 018	168	5, 306
Tibia	9	382	1, 557	3	144	4, 679	176	6, 950
Fibula	2	31	245	8		957	24	1, 267
Total	372	1, 845	1, 849	176	259	8, 654	368	13, 523
	Shoulder	Elbow	Wrist	Shoulder and elbow	Elbow and wrist	Not stated	Deaths	Total
Humerus	591	1, 332	53	145	79	2, 128	112	4, 440
Ulna	6	425	859	6	131	2, 269	102	3, 798
Radius	1	233	162	4	30	739	24	1, 193
Total	598	1, 990	1, 074	155	240	5, 136	238	9, 431
Grand total								22, 954

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.

TABLE 37.—*Fractures of long bones of United States veterans of the World War, showing bone involved, location and character of the fracture and amputation, and deaths, January 1, 1926* [a]

Bones	Fracture															
	Location															
	Head		Neck		Upper		Middle		Lower		Condyle		Malleolus		Elbow	
	Fracture	Amputation	Fracture	Amputation	Fracture	Amputation	Fracture	Amputation	Fracture	Amputation	Fracture	Amputation	Fracture	Amputation	Fracture	Amputation
Femur	162	29	183	1	709	504	858	795	967	410	81	----	----	----	----	----
Tibia	59	----	8	----	453	----	443	----	582	----	13	----	86	----	----	----
Fibula	24	----	4	----	107	----	170	----	530	----	7	----	57	----	----	----
Humerus	238	88	90	4	794	297	539	151	1,108	145	309	----	1	----	4	----
Ulna	30	----	----	----	335	----	212	----	297	----	2	----	----	----	1	----
Radius	66	----	7	----	198	----	231	----	550	----	4	----	1	----	----	----
Tibia, fibula	19	2	2	----	306	413	708	475	1,570	232	17	----	100	----	1	----
Radius, ulna	38	----	9	1	261	123	309	130	854	164	6	----	----	----	----	----
Total	636	119	303	6	3,163	1,337	3,470	1,551	6,458	951	439	----	245	----	6	----

Bones	Fracture									Amputation						Deaths	Total [b]
	Location				Further location									Reamputation			
	Knee		Not stated		Simple		Compound			Fracture		Due to disease					
	Fracture	Amputation	Fracture	Amputation	Right	Left	Right	Left	Not stated	Right	Left	Right	Left	Right	Left		
Femur	1	----	486	2	382	354	1,181	1,200	330	698	718	49	41	111	124	168	5,356
Tibia	1	----	617	----	251	281	670	738	322	----	----	----	----	----	----	70	2,312
Fibula	1	----	340	----	207	175	294	346	218	----	----	----	----	----	----	24	1,264
Humerus	----	----	549	3	259	292	1,361	1,298	422	324	315	4	3	23	19	112	4,432
Ulna	----	----	282	----	97	107	320	458	177	----	----	----	----	----	----	24	1,183
Radius	----	----	289	----	204	159	349	424	210	----	----	----	----	----	----	35	1,381
Tibia, fibula	1	----	631	19	560	498	852	944	501	413	489	53	34	55	97	126	4,622
Radius, ulna	----	----	439	3	329	253	477	514	343	160	230	4	3	11	13	67	2,404
Total	4	----	3,633	27	2,289	2,119	5,504	5,922	2,523	1,595	1,752	110	81	200	253	606	22,954

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] The difference in bone totals, in this table, is due to preference in tabulation being given to the amputated minor bone, where the major one was not amputated.

TABLE 38.—*Amputations as a result of fractures of long bones of United States veterans of the World War, by bone or bones involved, amputation levels, and interval elapsing between injury and amputation, and deaths, January 1, 1926* [a]

Bone involved and amputation level	Interval elapsing between injury and amputation											
	Days				Months					Over 4 years	Deaths [b]	Total
	1–3	4–7	8–15	16–31	2–6	7–12	13–24	25–36	37–48			
Femur:												
Upper	300	47	23	46	70	18	10	9	9	2	22	556
Middle	454	71	33	63	95	13	27	17	15	7	42	837
Lower	265	24	26	21	34	12	8	6	9	5	11	421
Not stated	1								1		1	3
Total	1,020	142	82	130	199	43	45	32	34	14	76	1,817
Tibia and fibula:												
Upper	260	25	14	20	34	13	16	11	14	8	19	434
Middle	288	19	21	33	30	18	23	19	18	6	19	494
Lower	144	9	9	10	20	5	7	10	12	6	11	243
Not stated	8				1		1	1	3	5		19
Total	700	53	44	63	85	36	47	41	47	25	49	1,190
Humerus:												
Upper	317	20	17	10	10	3	5	4	2	1	23	412
Middle	121	13	4	5	3	1	1	1	1	1	12	163
Lower	118	9	3	3	3	2	2	1	3	1	4	149
Not stated	1							1	1			3
Total	557	42	24	18	16	6	8	7	7	3	39	727
Radius and ulna:												
Upper	96	9	6	5	1	3	1	2		1	6	130
Middle	114	2	3	2	5	3			1		6	136
Lower	144	3	2	4	5	2	1		2	1	11	175
Not stated	1							1		1		3
Total	355	14	11	11	11	8	2	3	3	3	23	444
Grand total	2,632	251	161	222	311	93	102	83	91	45	187	4,178

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Death not necessarily a result of amputation.

TABLE 39.—*Amputations as a result of fractures of long bones of United States veterans of the World War, by character and degree of disability, bone or bones involved, amputation levels, and deaths, January 1, 1926* [a]

Character and degree of disability	Bone or bones involved									
	Femur					Tibia and fibula				
	Upper	Middle	Lower	Not stated	Total	Upper	Middle	Lower	Not stated	Total
Temporary partial:										
30-39	1				1					
40-49						2				2
50-59							1	1		2
60-69						1	2			3
70-79						1	2	3		6
80-89			1		1		1			1
Temporary total	21	22	9	1	53	19	16	14	9	58
Total temporary ratings	22	22	10	1	55	23	22	18	9	72
Permanent partial:										
20-29	1				1					
30-39									1	1
40-49			1		1	327	397	174	5	903
50-59	3	14	304	1	322	15	5	10	3	33
60-69	33	643	49		725	12	21	2		35
70-79	32	36	7		75	4	1	2		7
80-89	384	34	11		429	7	4	3		14
90-99	9	2	2		13					
Permanent total	50	44	26		120	27	25	23	1	76
Total permanent ratings	512	773	400	1	1,686	392	453	214	10	1,069
Total rated cases	534	795	410	2	1,741	415	475	232	19	1,141
Deaths	22	42	11	1	76	19	19	11		49
Grand total	556	837	421	3	1,817	434	494	243	19	1,190

Character and degree of disability	Bone or bones involved										Grand total
	Humerus					Ulna and radius					
	Upper	Middle	Lower	Not stated	Total	Upper	Middle	Lower	Not stated	Total	
Temporary partial:											
30-39											1
40-49											2
50-59											2
60-69											3
70-79		1			1						7
80-89	1				1						3
Temporary total	2	2			4		2			2	117
Total temporary ratings	3	3			6		2			2	135
Permanent partial:											
20-29											1
30-39											1
40-49											904
50-59	1				1	3	42	77	2	124	480
60-69						53	20	6		79	839
70-79		6	46	1	53	56	57	66	1	180	315
80-89	313	135	92		540	7	4	5		16	999
90-99	56	2	2	1	61						74
Permanent total	16	5	5	1	27	5	5	10		20	243
Total permanent ratings	386	148	145	3	682	124	128	164	3	419	3,856
Total rated cases	389	151	145	3	688	124	130	164	3	421	3,991
Deaths	23	12	4		39	6	6	11		23	187
Grand total	412	163	149	3	727	130	136	175	3	444	4,178

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.

Tables 40 to 73, inclusive, show the character and degree of impairment for each long bone or for associated bones, according to the progress made at intervals of three months. Separate tables have been prepared for each bone when there was a series of 100 cases or more to each 10 per cent.

FEMUR FRACTURES

The femur fractures number 5,138, or 23 per cent of the total fractures, and comprise the most serious group of injuries, not only because of the prolonged duration of time required to reach a stationary level but also because of the very high degree of disability. Of the 5,138 cases, 259, or 5 per cent, required a period of 2 years to reach their stationary level; 435, or 9 per cent, required three years; 637, or 12 per cent, required four years; 1,185, or 23 per cent, required five years; and 2,622, or 51 per cent, required more than five years. Thus 26 per cent of the changes in rating occurred before the end of the fourth year, so that 74 per cent of the femurs required more than four years to reach a stationary level. These cases of fractured femurs were rated as follows: Two hundred and seventy, or 5 per cent, were less than 10 per cent: 1,673, or 33 per cent, between 10 and 29; 726, or 14 per cent, between 30 and 49; 1,671, or 33 per cent, between 50 and 79; 484, or 9 per cent, between 80 and 99; 314, or 6 per cent, were rated 100. Amputations of the thigh contributed largely to the higher ratings for, among the 1,671 cases rated 50–79, there were 1,122 amputations; among the 484 rated 80–99 there were 443 amputations; and among the 314 rated 100 there were 173 amputations. Of the 141 fractures rated 100 per cent yet not amputated, 53 were under hospitalization. It should be stated that 100 per cent is the rating awarded hospital cases. Shortening occurred in 2,155 or 41.94 per cent of these cases, which also combined to increase the rating. The severity of many of these injuries was increased further by the complication due to an injury of an associated nerve in 418 cases.

TIBIA AND FIBULA FRACTURES

Tibia and fibula fractures number 4,485, or 20 per cent, of the total fractures. They make up another important group in which 226, or 5 per cent, required two years to reach their stationary level; 453, or 10 per cent, required three years; 562, or 13 per cent, required four years; 1,027, or 23 per cent, required five years; and 2,194, or 49 per cent, required more than five years. Thus 28 per cent of the changes in rating occurred before the end of the fourth year, and 72 per cent required more than four years to reach a stationary level. Their degrees of rating are as follows: Seven hundred and sixty-four, or 17 per cent, were less than 10; 1,968, or 44 per cent, were between 10 and 29; 1,272, or 28 per cent, between 30 and 49; 244, or 5 per cent, between 50 and 79; 21, or 1 per cent, between 80 and 99; and 216, or 5 per cent, were 100. Amputations of the lower leg contributed to the higher ratings. Among the 1,272 cases rated 30–49 there were 906 amputations; among the 244 cases rated 50–79 there were 86 amputations: among the 21 cases rated 80–99 there were 15 amputations: and among the 216 cases rated 100 there were 134 amputations. Of the 82 fractures rated 100 per cent yet not amputated, 58 were under hospital care. There were also 273 associated nerve injuries. For nonunion, 97

operations were performed in which bone grafts were employed; in 60 cases Lane plates were used. Shortening occurred in 982 cases, which also increased the ratings.

TIBIA FRACTURES

Fractures of the tibia number 2,289 or 10 per cent and are somewhat less serious than those of the previously mentioned bones; 118, or 5 per cent, required two years; 212, or 9 per cent, required three years; 266, or 12 per cent, required four years; 478, or 21 per cent, required five years; and 1,129, or 49 per cent, required more than five years; 86, or 4 per cent, unclassified; thus 26 per cent of the changes in rating occurred before the end of the fourth year and 74 per cent required more than four years. Their degrees of rating were as follows: Five hundred and ninety-eight, or 26 per cent, were less than 10; 1,314, or 57 per cent, were between 10 and 29; 196, or 8 per cent, between 30 and 49; 107, or 5 per cent, between 50 and 79; 15, or 1 per cent, between 80 and 99; and 59, or 3 per cent, were 100. In 160 cases there was an associated nerve injury.

FIBULA FRACTURES

Improvement begins earlier in these cases which number 1,243 or 6 per cent; 89, or 7 per cent, required two years to reach their stationary level; 123, or 10 per cent, required three years; 153, or 12 per cent, required four years; 221, or 18 per cent, required five years; 454, or 37 per cent, required more than five years; 203, or 16 per cent, are unclassified; thus 29 per cent of the changes in rating occurred before the end of the fourth year, and 71 per cent required more than four years. Their degrees of rating were as follows: Five hundred and ten, or 41 per cent, are less than 10; 616, or 49 per cent, between 10 and 29; 88, or 7 per cent, between 30 and 49; 20, or 2 per cent, between 50 and 79; 4, or 0.4 per cent, between 80 and 99; and 5, or 0.6 per cent, were 100. In 164 cases there was an associated nerve injury.

HUMERUS FRACTURES

These cases number 4,328, or 19 per cent, and make up another group of severe disabilities; 214, or 5 per cent, required 2 years to reach their stationary level; 303, or 7 per cent, required 3 years; 492, or 11 per cent, required 4 years; 954, or 22 per cent, required 5 years; 2,365, or 55 per cent, required more than 5 years. Thus only 23 per cent of the changes in rating occurred before the end of the fourth year, and 77 per cent required more than 4 years to reach a stationary level. Their degrees or rating were as follows: Four hundred and sixteen, or 10 per cent, were less than 10; 1,752, or 40 per cent, were between 10 and 29; 734, or 17 per cent, between 30 and 49; 637, or 15 per cent, between 50 and 79; 709, or 16 per cent, between 80 and 99; and 80, or 2 per cent, were 100. Amputations of the upper arm contributed to the higher ratings. Among the 637 cases rated 50–79 there were 55 amputations; among the 709 cases rated 80–99 there were 602 amputations; among the 80 cases rated 100 there were 31 amputations. The severity in this group was very largely increased because of an associated nerve injury in 1,086 cases, for which many operations have been performed. Also, more than 250 operations were performed for nonunion, in which bone grafts, Lane plates and wire sutures were used.

RADIUS AND ULNA FRACTURES

Radius and ulna fractures number 2,340, or 10 per cent of the total fractures. In this group 132 cases, or 6 per cent, required 2 years to reach their stationary level; 185, or 8 per cent, required 3 years; 311, or 13 per cent, required 4 years; 538, or 23 per cent, required 5 years; 1,154, or 49 per cent, required more than 5 years; 30, or 1 per cent, were unclassified. Thus 27 per cent of the changes in rating occurred before the end of the fourth year and 73 per cent required more than 4 years to reach a stationary level. Their ratings were as follows: Three hundred and ninety-nine, or 17 per cent, were less than 10 per cent; 1,003, or 43 per cent, were between 20 and 29; 294, or 12 per cent, between 30 and 49; 581, or 25 per cent, between 50 and 79; 24, or 1 per cent, between 80 and 99; 39, or 2 per cent, were rated 100. Amputations of the lower arm contributed to the higher ratings. Among the 581 cases rated 50–79 there were 383 amputations; among the 24 cases rated 80–99 there were 16 amputations; and among the 39 cases rated 100 there were 22 amputations. There were also 417 associated nerve injuries. For nonunion 104 operations were performed, in which bone grafts were employed in 82 cases and Lane plates and wire sutures in 22 cases.

RADIUS FRACTURES

Radius fractures numbered 1,356, or 6 per cent, of the total fractures; 110, or 8 per cent of the cases, required 2 years to reach their stationary level; 109, or 8 per cent, required 3 years; 145, or 11 per cent, required 4 years; 300, or 22 per cent, required 5 years; 591, or 44 per cent, required more than 5 years; 101, or 7 per cent, were unclassified. Thus 27 per cent of the changes in rating occurred before the end of the fourth year and 73 per cent required more than 4 years. Their ratings were as follows: Three hundred and twenty-four, or 24 per cent, were less than 10 per cent; 745, or 55 per cent, between 10 and 29; 158, or 12 per cent, between 30 and 49; 111, or 8 per cent, between 50 and 79; 5, or 1 per cent, between 80 and 99; 13, or 0.9 per cent, were rated 100. In 272 cases there was an associated nerve injury.

ULNA FRACTURES

Ulna fractures numbered 1,169, or 5 per cent of the total fractures; 60, or 5 per cent of the cases, required 2 years to reach their stationary level; 83, or 7 per cent, required 3 years; 129, or 11 per cent, required 4 years; 230, or 20 per cent, required 5 years; 498, or 43 per cent, required more than 5 years; 169, or 14 per cent, unclassified; thus 23 per cent of the changes in rating occurred before the end of the fourth year and 77 per cent required more than 4 years. This large percentage is due to the fact that in 347, or 33.68 per cent of cases, there was an associated nerve injury which materially delayed the recovery. Their ratings were as follows: Two hundred and forty-seven, or 21 per cent, were less than 10; 664, or 57 per cent, were between 10 and 29; 169, or 14 per cent, between 30 and 49; 76, or 7 per cent, between 50 and 79; 5, or 0.4 per cent, between 80 and 99; 8, or 0.6 per cent, were 100.

TABLE 40.—*Fractured femur, United States veterans of the World War, rated less than 10 per cent on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]: 10–19 Temporary	20–29 Temporary	20–29 Permanent	30–39 Permanent	40–49 Permanent	50–59 Permanent	60–69 Permanent	80–89 Temporary	80–89 Permanent	100 Temporary	Total: Less than 10 per cent	Total: Temporary	Total: Permanent	Total [c]
3											2			2
6											2			2
9											7			7
12											1			1
15											3			3
18											4			4
21											1			1
24											4			4
Total											24			24
27	1										3	1		4
30											4			4
33	1										9	1		10
36	1										8	1		9
39											4			4
42							1			1	3	1	1	5
45										1	5	1		6
48											4			4
Total	3						1			2	40	5	1	46
51											5			5
54			1			1					5		2	7
57				1							6		1	7
60									1		3		1	4
63	1										2	1		3
66		1								1	5	2		7
69								1				1		1
72	1	1							1			2	1	3
Total	2	2	1	1		1		1	2	1	26	6	5	37
75										1	3	1		4
78										2		2		2
84										2	1	2		3
87					1								1	1
93		1										1		1
Total		1			1					5	4	6	1	11
99					1								1	1
Grand total	5	3	1	1	2	1	1	1	2	8	94	17	8	119

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 41.—*Fractured femur, United States veterans of the World War, rated 10–29 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]																		Total			
	10–19		20–29		30–39		40–49		50–59		60–69		70–79		80–89		100					
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Less than 10 per cent	Temporary	Permanent	Total [c]
3	1	1		1																1	2	3
6	3	3	4																	7	3	10
9	2	1	1																	3	1	4
12	2	1	1	1																3	2	5
15	2	3	3	1															1	5	4	10
18	3	2	2	2															3	5	4	12
21	3		6	2															1	9	2	12
24	3	6	1														1		2	5	6	13
Total	19	17	18	7													1		7	38	24	69
27	4	3	1	2															2	5	5	12
30	2	6	5	3		1		1			1							1	3	8	12	23
33	7	5	7	9		1													3	14	15	32
36	7	8	10	7															8	17	15	40
39	8	9	8	9	1					1									6	17	19	42
42	10	11	3	8		1		1	1										8	14	21	43
45	5	13	3	12				1				1				1			10	8	28	46
48	7	18	1	13		2		2									3		5	11	35	51
Total	50	73	38	63	1	5		5	1	1	1	1				1	3	1	45	94	150	289
51	8	22	7	21		2		2	2								2	1	13	19	48	80
54	4	26	1	20		1		1	1	1		1					2		8	8	50	66
57	6	26	4	32		4		3				1					1		7	11	66	84
60	9	47	7	44	1	7		3	1	1	1	2				1	1		13	20	105	138
63	4	58	5	55		7	1	1	2	1		1		1		1	1		17	13	125	155
66	12	70	3	50		6		7	1		1	1		1			1		17	18	135	170
69	5	59	6	53	1	13		3		3		1				2	2		7	14	134	155
72	4	49	3	32	1	7		7	1				1	1		1	2		7	12	97	116
Total	52	357	36	307	3	47	1	27	8	6	2	7	1	3		5	12	1	89	115	760	964
75	3	30	9	22	2	9	1	3		5	1	6			1	1	4		4	21	76	101
78	4	17	6	25		4		4	1	4		1					4		4	15	55	74
81	2	8	2	7	2	1		2		5		1					2		4	8	24	36
84	1	8	1	4	1	2				2		1		1						3	18	21
87		8		5	1	2		1		1										1	17	18
90		2		3		2		1				1					1		1	1	9	11
93		3		1												1					5	5
96	1	1																		1	1	2
Total	11	77	18	67	6	20	1	11	1	17	1	10		1	1	2	11		13	50	205	268
99				1																	1	1
102		2																			2	2
108		2																			2	2
Total		4		1																	5	5
Grand total	132	528	110	445	10	72	2	43	10	24	4	18	1	4	1	8	27	2	154	297	1,144	1,595

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

46997—27——35

TABLE 42.—*Fractured femur, United States veterans of the World War, rated 30–49 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]																	Total		
	10–19		20–29		30–39		40–49		50–59		60–69		70–79		80–89	100	Less than 10 per cent			
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Temporary		Temporary	Permanent	Total [c]
6						2													2	2
9						3													3	3
15				1	1													1	1	2
18					1	1	1											2	1	3
21					1	2												1	2	3
24					1	2												1	2	3
Total				1	4	10	1											5	11	16
27						2	2	2										2	4	6
30	1		1		1	4	1	3									1	4	7	12
33			1	1	1	4	3	1										5	6	11
36		2	1		3	4	3	1			1							8	7	15
39			1	4	2	3	2	3										5	10	15
42	2			2		6	4	1				1					1	6	10	17
45	1	1			1	4	2	3			1						2	5	8	15
48		2		3		5	1	4		1								1	15	16
Total	4	5	4	10	8	32	18	18		1	2	1					4	36	67	107
51	1	1	1	7		7		2		1								2	18	20
54	2	8		3	2	8	1	5		4								5	28	33
57	2	3		10	2	15		5	1	3		1		1		1	2	6	38	46
60	3	10	1	9	2	16	1	8	1	4		1					1	8	48	57
63		10		24	2	17		11		6		4		1		1	1	3	73	77
66		12		20	2	23		19		4		2	1				1	3	80	84
69	1	8	1	14	2	26	1	12	2	6		4		1			1	7	71	79
72	1	6		13	1	16		12		5		2		1		1		3	55	58
Total	10	58	3	109	13	128	3	74	4	33		14	1	4		3	6	37	411	454
75	1	2		7		10	1	10	2	5		3		1	2	2		6	40	46
78		4	2	6		11		7	2	7		1		1		1		5	37	42
81	1	2		4	1	8		6		2		3				2		4	25	29
84	1			2		6		1		1		2				1		2	12	14
87						1	1			1		1				2		3	3	6
90												1							1	1
93		1						1											2	2
Total	3	9	2	19	1	36	2	25	4	16		11		2	2	8		20	120	140
99												1							1	1
108															1				1	1
Total												1			1				2	2
Grand total	17	72	9	130	26	206	24	117	8	50	2	27	1	6	3	11	10	98	611	719

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 43.—*Fractured femur, United States veterans of the World War, rated 50–79 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]																		Total		
	10–19		20–29		30–39		40–49		50–59		60–69		70–79		80–89	100		Less than 10 per cent			
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Temporary	Permanent		Temporary	Permanent	Total [c]
6										2										2	2
9									1			1							1	1	2
12										1		2								3	3
15										1										1	1
18												2								2	2
21									1			1							1	1	2
24			1							1				1		1			2	2	4
Total			1						2	5		6		1		1			4	12	16
27									1	1		3		1	1			1	1	6	8
30											1								1		1
33			1						1	2	2	2				1			5	4	9
36				1						1		1								3	3
39						1			1	5	1	2	1						3	8	11
42		1		1		1				5	1	3		1					1	12	13
45		2	1	3				1		2		3						1	1	11	13
48			1	1	1			2	1	9		5		3					3	20	23
Total		3	3	6	1	2		3	4	25	5	19	1	5	1	1		2	15	64	81
51								2		4		7		2						15	15
54				1			1	4	1	6		7		1		1			3	19	22
57		5		4		4		4		11	1	5		3		3			4	36	40
60			1	2		2	1	2	1	5	1	10		4		2		1	6	25	32
63		5	2	1		5		9	1	9		8		3		1		1	4	40	45
66	1	3		3		2		16	2	13	1	12		3	1	1		1	5	53	59
69		2		6		4		10	2	13	1	9	1	2	1	2			6	47	53
72		1		5		4		6		5	2	7	1		4		1		3	33	36
Total	1	16	3	22		21	2	53	7	66	6	65	2	18	6	10	1	3	31	268	302
75	1			3		3		6	1	7		11		2		3			5	32	37
78				1				4		3	2	4		3		2			4	15	19
81				2		1		1		7		2		3				1		16	17
84						1		2	1	6		2		1	1	1			2	13	15
87												2	1	1					1	3	4
90										1										1	1
93										1										1	1
Total	1			6		5		13	2	25	2	21	1	10	1	6		1	12	81	94
Grand total	2	19	7	34	1	28	2	69	15	121	13	111	4	34	8	18	1	6	62	425	493

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 44.—*Fractured femur, United States veterans of the World War, rated 80–99 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]									Total		
	20–29	30–39	50–59	60–69	70–79		80–89	90–99	100			Total [c]
	Permanent	Permanent	Permanent	Permanent	Temporary	Permanent	Permanent	Permanent	Temporary	Temporary	Permanent	
18									1	1		1
27							2	1			3	3
30							1				1	1
33								1			1	1
36							3				3	3
42							1		1	1	1	2
45						1	3				4	4
48							6				6	6
Total						1	16	2	1	1	19	20
51			1	1			8				10	10
54		1					6				7	7
57	1					1	2	1			5	5
60		1		1			6				8	8
63							5				5	5
66				3			11	2			16	16
69							7	1			8	8
72			1		1	2	6			1	9	10
Total	1	2	2	5	1	3	51	4		1	68	69
75			2				3		1	1	5	6
78			1	1							2	2
81							1				1	1
96			1								1	1
Total			4	1			4		1	1	9	10
Grand total	1	2	6	6	1	4	71	6	3	4	96	100

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 45.—*Fractured femur, United States veterans of the World War, rated 100 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]: 10–19 Temporary	10–19 Permanent	20–29 Temporary	20–29 Permanent	30–39 Temporary	30–39 Permanent	40–49 Temporary	40–49 Permanent	50–59 Temporary	50–59 Permanent	60–69 Temporary	60–69 Permanent	70–79 Temporary	70–79 Permanent	80–89 Temporary	80–89 Permanent	90–99 Permanent	100 Temporary	100 Permanent	Total: Less than 10 per cent	Total: Temporary	Total: Permanent	Total [c]
6										1		1						2			2	2	4
9	1			1						2						1					1	4	5
12				1				1	1	3		1				2			2	1	1	10	12
15	1			2								3				1	2	3	2		4	10	14
18				2						5		8				3		3	4		3	22	25
21	1		2	1				1	1	5		12		3		6		1	5		5	33	38
24									1	7		16		2		4		2	3		3	32	35
Total	3		2	7				2	3	23		41		5		17	2	11	16	1	19	113	133
27	1			1	2	1				2		8		5		6		3	1		6	24	30
30	1			2				1		10		18		3		9			6		1	49	50
33	1			1		2		2	1	16		24		2		14		2	7		4	68	72
36		1		1		1		1		12		20		2		15		11	11	1	11	64	76
39	1	1	1	1					2	14		15	1	2		20		5	16		10	69	79
42		1		2	1				2	9		22		1		13	1	1	15	2	4	64	70
45	1	2	1	2	1	1	1	2	1	5		22	1	6		18		3	9		9	67	76
48	1		2	2						16		20		1		18		7	9		10	66	76
Total	6	5	4	12	4	5	1	6	6	84		149	2	22		113	1	32	74	3	55	471	529
51		1	1	3				6	3	21		35	1	4		17		7	8		12	95	107
54	1	1	1	8		3	1	2		21		34	1	5		22		3	5		7	101	108
57		3		6	2	2		4		27		44	1	2		26		4	4		7	118	125
60	1	6	2	6	1	2		4	2	22	1	64		9		23		10	5	1	17	141	159
63	2	5	1	6	1	6		4		30	2	66		3		25	1	6	3		12	149	161
66		4		12	1	4	1	12	1	23		66	1	16	1	36		4			9	173	182
69		10		6		4		4	2	35		68	3	11	1	31	1	8	4		14	174	188
72		4		5		5		4		24		43	1	8		25		8			9	118	127
Total	4	34	5	52	5	26	2	40	8	203	3	420	8	58	2	205	2	50	29	1	87	1,069	1,157
75		2	1	6		3	2	8	1	15	1	35	1	9		20		9	2		15	100	115
78	1			3	1	3		4	1	15	2	22		2		9		4	1		9	59	68
81		2		3	1	1		2	2	11		14		3		7		6	1		9	44	53
84		1		3		3		1		6		10		1		3		6			6	28	34
87			1			1				1		5	1	2		2	1		2	1	2	14	17
90										1				2								3	3
93																		1			1		1
96				1																		1	1
Total	1	5	2	16	2	11	2	15	4	49	3	86	2	19		41	1	26	6	1	42	249	292
102									1												1		1
Grand total	14	44	13	87	11	42	5	63	22	359	6	696	12	104	2	376	6	119	125	6	204	1,902	2,112

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 46.—*Fractured tibia, United States veterans of the World War, rated less than 10 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]				Total			
	10–19		10–29 temporary	100 temporary	Less than 10 per cent	Temporary	Permanent	Total [c]
	Temporary	Permanent						
3					12			12
6					2			2
9					2			2
12					4			4
15					4			4
18					2			2
21	1	1	1			2	1	3
24					3			3
Total	1	1	1		29	2	1	32
27					7			7
30					14			14
33				1	14	1		15
36					15			15
39					11			11
42	1				11	1		12
45					11			11
48		1			12		1	13
Total	1	1		1	95	2	1	98
51					6			6
54		1			8		1	9
57	1	1			9	1	1	11
60		1			8		1	9
63		3			8		3	11
66					3			3
69					6			6
72					5			5
Total	1	6			53	1	6	60
75	2	4			7	2	4	13
78		1	1		3	1	1	5
81		1			2		1	3
84					2			2
87		1					1	1
93					1			1
Total	2	7	1		15	3	7	25
Grand total	5	15	2	1	192	8	15	215

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 47.—*Fractured tibia, United States veterans of the World War, rated 10–29 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]													Total [c]			
	10–19		20–29		30–39		40–49		50–59		70–79		100	Less than 10 per cent	Temporary	Permanent	Total [c]
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary				
3		1														1	1
6	4		4												8		8
9			3												3		3
12	2	1												3	2	1	6
15	6		1	1										2	7	1	10
18		2	2	2										1	2	4	7
21	3		2	2										4	5	2	11
24	5	2	2	1										4	7	3	14
Total	20	6	14	6										14	34	12	60
27	7	2	1											7	8	2	17
30	6	1	2	2										13	8	3	24
33	19	3	7	1									1	17	27	4	48
36	7	5	7			1								16	14	6	36
39	16	5	8	2										23	24	7	54
42	10	1	5	2	1					1				13	16	4	33
45	7	3	5	5									1	21	13	8	42
48	9	11	3	3	1									20	13	14	57
Total	81	31	38	15	2	1				1			2	130	123	48	301
51	7	20	4	6		1					1			18	12	27	57
54	10	34	5	7				2						21	15	43	79
57	10	44	3	11	1	1		2						22	14	58	94
60	10	52	7	13	1	1				1				28	18	67	113
63	14	67	8	18	1	2		1	1					23	24	88	135
66	4	76	2	26		3				1			2	26	8	106	140
69	7	79	4	21			1	3	1	2				25	13	105	143
72	5	66	2	23		6		2					2	25	9	97	131
Total	67	438	35	125	3	14	1	10	2	4	1		4	188	113	591	892
75	5	28	5	16		2		2					1	15	11	48	74
78	7	20	3	7		3		2	1			2	1	5	12	34	51
81	2	14	4	8	1	2		1	2				4	9	13	25	47
84	2	7		3					1	1			3	2	6	11	19
87	2	8		1		1					1		1		4	10	14
90		1												2		1	3
93	1	1				4		1						1	1	6	8
96		1												2		1	3
Total	19	80	12	35	1	12		6	4	1	1	2	10	36	47	136	219
99														1			1
102		1														1	1
Total		1												1		1	2
Grand total	187	556	99	181	6	27	1	16	6	6	2	2	16	369	317	788	1,474

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 48.—*Fractured tibia, United States veterans of the World War, rated 30–49 per cent disabled on first rating examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b] 10–19 Temporary	10–19 Permanent	20–29 Temporary	20–29 Permanent	30–39 Temporary	30–39 Permanent	40–49 Temporary	40–49 Permanent	50–59 Permanent	60–69 Permanent	70–79 Permanent	80–89 Temporary	Less than 10 per cent	Total Temporary	Total Permanent	Total [c]
6						1	1							1	1	2
9	1													1		1
24				1											1	1
Total	1			1		1	1							2	2	4
27					1								1	1		2
30					1	1							1	1	1	3
33	1			1	1									2	1	3
36	2		2		2									6		6
39	2	2			1		1							4	2	6
42					1	1								1	1	2
45													1			1
48		1	1	1	2								1			6
Total	5	3	3	2	9	2	1						4	18	7	29
51		1				1		1					1		3	4
54	1	4		1	1	2		1						2	8	10
57		4		4	1	1	1	1	1				1	2	11	14
60		5		3	1	3	2	2						3	13	16
63	1	9		3		4		1		2			2	1	19	22
66	1	8	1	4	1	5		1	1				1	3	19	23
69	1	7	1	12	1	10		2	1				4	3	32	39
72		5	1	6	1	6		1	1				1	2	19	22
Total	4	43	3	33	6	32	3	10	4	2			10	16	124	150
75			1	1		4	1	1	1					2	7	9
78		5		3		5		1			2	1		1	16	17
84								1							1	1
87								1	1						2	2
90									1						1	1
Total		5	1	4		9	1	4	3		2	1		3	27	30
Grand total	10	51	7	40	15	44	6	14	7	2	2	1	14	39	160	213

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 49.—*Fractured tibia, United States veterans of the World War, rated 100 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]																	Total			
	10–19		20–29		30–39		40–49		50–59		60–69		70–79		80–89	100					
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Temporary	Permanent	Less than 10 per cent	Temporary	Permanent	Total [c]
9		1		1				1								1			1	3	4
12	1	1	1	1														1	2	2	5
15				1																1	1
18			2						1					1		1		1	4	1	6
21	1															1			2		2
24	1							1								1	1		2	2	4
Total	3	2	3	3				2	1					1		4	1	2	11	9	22
27	1					1												1	1	1	3
30				1												1			1	1	2
33	2			1							2				1	1	1	1	5	3	9
36	1		1					1					1			2	1	1	5	2	8
39				2					1							2		1	3	2	6
42			1		1												2		2	2	4
45				2				2	1									1	1	4	6
48		2			1				2	1						1	5		4	8	12
Total	4	2	2	6	2	1		3	4	1	2		1		1	7	9	5	22	23	50
51		1		2					1	1				1		1	2	1	2	7	10
54	1	3		1			1	2		2		2				1		1	3	10	14
57	1	1		4		1				1	1	1	1		2				3	10	13
60	1	5	1	2		2		2	1	2		1			1			1	3	15	19
63		2	2	3		4		3	1	1						2		2	5	13	20
66		12	1	5		1		2	1	1		1		1		1		2	3	23	28
69		10		11		1		3	1	2					1	3		1	4	28	33
72		9		7		2	1	2	2	1	1		2		3			1	6	24	31
Total	3	43	4	35		11	2	14	7	11	2	5	3	2	7	8	2	9	29	130	168
75		4	1	6		2	1	4		3			1	1	1	3		2	6	21	29
78			1		1	1		1	1	1		1				1			4	4	8
81	1	1	1	3				3		1			1			1	1		4	9	13
84										1		1	1		1	1			2	3	5
87						1								1						2	2
90																1			1		1
93					1											1			2		2
Total	1	5	3	9	2	4	1	8	1	6		2	3	2	2	8	1	2	19	39	60
99									1										1		1
Grand total	11	52	12	53	4	16	3	27	14	18	4	7	7	5	10	27	13	18	82	201	301

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 50.—*Fractured fibula, United States veterans of the World War, rated less than 10 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]				Total			Total [c]
	10–19		20–29	40–49	Less than 10 per cent	Temporary	Permanent	
	Temporary	Permanent	Permanent	Temporary				
3					27			27
6					2			2
9					1			1
12					6			6
15					2			2
18					2			2
21					1			1
24					6			6
Total					47			47
27					6			6
30					6			6
33					17			17
36					15			15
39					7			7
42					7			7
45					15			15
48					8			8
Total					81			81
51	1				7	1		8
54					5			5
57					9			9
60		1	1		4		2	6
63					5			5
66					7			7
69		1			2		1	3
72		1			5		1	6
Total	1	3	1		44	1	4	49
75	1	1		1	4	2	1	7
78		1			3		1	4
81		1			5		1	6
84					1			1
87	1				4	1		5
90	1					1		1
Total	3	3		1	17	4	3	24
Grand total	4	6	1	1	189	5	7	201

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the 6-year period of the study.

TABLE 51.—*Fractured fibula, United States veterans of the World War, rated 10–29 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]												Total			
	10–19		20–29		30–39		40–49		50–59		100					
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Less than 10 per cent	Temporary	Permanent	Total [c]
3	1		1	1										2	1	3
6	3		2											5		5
9													5			5
12		1											3		1	4
15	2			1									1	2	1	4
18	1		1										2	2		4
21	1		2										7	3		10
24	2												5	2		7
Total	10	1	6	2									23	16	3	42
27	2												10	2		12
30	5	1											18	5	1	24
33	4	3	3										11	7	3	21
36	6	2	4	3									7	10	5	22
39	7	6	2	6									14	9	12	35
42	6	1	1										15	7	1	23
45	6	3	1					1					21	7	4	32
48	4	2	3	2									15	7	4	26
Total	40	18	14	11				1					111	54	30	195
51	2	6	1	1		1		1					20	3	9	32
54	8	13		2		1							18	8	16	42
57	5	13		6		1	1						17	6	20	43
60	6	32	4	6		3		1	1				23	11	42	76
63	8	40	1	6	1	1							26	10	47	83
66	5	49	1	9		3							20	6	61	87
69	8	39		9		2		2					17	8	52	77
72	7	32	4	8		1		1					11	11	42	64
Total	49	224	11	47	1	13	1	5	1				152	63	289	504
75	2	18	1	5		2	1						3	4	25	32
78	5	11		4	1					1		1	3	6	17	26
81	3	4	1	4	1					1			2	5	9	16
84	2	9		2									2	2	11	15
87		2				1							2		3	5
90				1											1	1
93				1											1	1
96											1			1		1
Total	12	44	2	17	2	3	1			2	1	1	12	18	67	97
99													1			1
Grand total	111	287	33	77	3	16	2	6	1	2	1	1	299	151	389	839

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the 6-year period of the study.

TABLE 52.—*Fractured tibia and fibula among United States veterans of the World War, rated less than 10 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]												Total			
	10–19		20–29		30–39	40–49	50–59		70–79	80–89	100					
	Temporary	Permanent	Temporary	Permanent	Permanent	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Less than 10 per cent	Temporary	Permanent	Total [c]
3													25			25
6													2			2
9													4			4
12													1			1
15													6			6
18													3			3
21													4			4
24													7			7
Total													52			52
27					1								4		1	5
30													10			10
33													26			26
36	1	1											17	1	1	19
39	1											1	17	1	1	19
42	1		1			1							10	2	1	13
45													12			12
48						1						1	13		2	15
Total	3	1	1		1	2						2	109	4	6	119
51													9			9
54	1	3		1		1	1						8	2	5	15
57	1	2				1		1					7	1	4	12
60	1		1	1		1							7	2	2	11
63	1	2									1		11	2	2	15
66	1	3								1			9	1	4	14
69		2			1	1					2	1	8	2	5	15
72		5									1		2	1	5	8
Total	5	17	1	2	1	4	1	1		1	4	1	61	11	27	99
75	1	2		1	1				1				3	2	4	9
78		2		2		2					1		2	1	6	9
81		3											3		3	6
84		3											1		3	4
87		1				1							3		2	5
90		1			1	1							1		3	4
93			1											1		1
Total	1	12	1	3	2	4			1		1		13	4	21	38
Grand total	9	30	3	5	4	10	1	1	1	1	5	3	235	19	54	308

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 53.—*Fractured tibia and fibula, United States veterans of the World War, rated 10–29 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]																Total			
	10–19		20–29		30–39		40–49		50–59		60–69		70–79		100					
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Less than 10 per cent	Temporary	Permanent	Total [c]
3	2																	2		2
6	1																	1		1
9			1															1		1
12	2		4	1													2	6	1	9
15	2	5	1														3	3	5	11
18	4	1	1	2													4	5	3	12
21	1	5	2					2									4	3	7	14
24	6		1														7	7		14
Total	18	11	10	3				2									20	28	16	64
27	4	3	3	1					1						1		8	9	4	21
30	7	3	4			1											19	11	4	34
33	23	5	6	6	1												23	30	11	64
36	10	5	8	4						1							20	18	10	48
39	21	5	11	3				2		1					2		22	34	11	67
42	20	18	2	9													20	22	27	69
45	12	16	7	2		1									3		36	22	19	77
48	15	18	2	13		1									1		29	18	32	79
Total	112	73	43	38	1	3		2	1	2					7		177	164	118	459
51	17	33	5	15		4									1		24	23	52	99
54	12	51	9	14		3	1	2		1					1		36	23	71	130
57	13	65	7	27		4		2					1		1	1	33	22	99	154
60	11	77	5	30		3		1		1		1			1		29	17	113	159
63	15	91	2	36		5			1								39	18	132	189
66	13	111	5	51	1	7		4							2	1	38	21	174	233
69	12	92	5	43	1	12		4	1	1		1			2		27	21	153	201
72	7	67	13	28		9		4				2		1	5		19	25	111	155
Total	100	587	51	244	2	47	1	17	2	3		4	1	1	13	2	245	170	905	1,320
75	11	47	5	22		6	1	3			2				2		14	21	78	113
78	3	35	5	20		7	1	5		1					2		10	11	68	89
81	1	21	3	13		1		3		1		1	1		3		6	8	40	54
84	5	17	3	7		1						1			3		5	11	26	42
87		7		6		2		3									4		18	22
90		5		2		1	1	2							1		2	2	10	14
93	1	1		1													2	1	2	5
96	1	1	2					1	1									4	2	6
Total	22	134	18	71		18	3	17	1	2	2	2	1		11		43	58	244	345
99								1											1	1
106				1															1	1
Total				1				1											2	2
Grand total	252	805	122	357	3	68	4	39	4	7	2	6	2	1	31	2	485	420	1,285	2,190

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 54.—*Fractured tibia and fibula, United States veterans of the World War, rated 30–49 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]														Total			
	10–19		20–29		30–39		40–49		50–59		60–69	70–79	100					
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Temporary	Temporary	Permanent	Less than 10 per cent	Temporary	Permanent	Total [c]
12	---	---	---	---	---	---	1	---	---	---	---	---	---	---	---	1	---	1
15	---	---	---	1	2	---	1	1	---	---	---	---	---	---	---	3	2	5
21	---	---	---	---	---	---	1	2	---	---	---	---	---	---	---	1	2	3
24	1	---	---	---	---	---	---	---	---	---	---	---	---	---	1	1	---	2
Total	1	---	---	1	2	---	3	3	---	---	---	---	---	---	1	6	4	11
27	---	---	---	---	3	---	1	1	---	---	---	---	---	---	---	4	1	5
30	1	1	---	2	---	1	---	1	---	---	---	---	---	---	2	1	5	8
33	1	---	---	1	---	2	---	2	---	---	---	---	1	---	---	2	5	7
36	1	---	---	3	3	---	---	2	---	---	---	---	---	---	2	4	5	11
39	1	---	---	---	1	2	---	7	---	---	---	---	---	---	1	2	9	12
42	1	---	3	1	2	2	---	2	---	1	---	---	---	---	2	6	6	14
45	1	---	1	2	1	2	---	3	---	---	---	---	---	---	1	3	7	11
48	---	2	---	4	1	1	---	7	---	1	---	---	---	---	1	1	15	17
Total	6	3	4	13	11	10	1	25	---	2	---	---	1	---	9	23	53	85
51	1	1	2	1	1	5	1	8	---	---	---	---	1	---	2	6	15	23
54	---	6	---	5	1	1	1	5	---	---	---	---	---	---	1	2	17	20
57	---	2	---	6	---	6	1	11	---	---	---	---	---	---	2	1	25	28
60	2	5	1	6	---	8	---	10	---	1	---	---	3	---	1	6	30	37
63	1	13	2	9	1	6	---	17	---	2	---	---	2	---	2	6	47	55
66	---	8	1	13	---	14	---	7	---	3	1	---	---	---	---	1	46	47
69	---	8	---	9	1	7	1	17	---	---	1	---	1	---	---	3	42	45
72	---	3	3	5	---	8	---	10	---	---	1	---	3	---	---	6	27	33
Total	4	46	9	54	4	55	4	85	---	6	3	---	10	---	8	31	249	288
75	---	8		2	1	2	---	11	---	4	1	---	---	---	---	1	28	29
78	1	1	---	8	1	2	1	3	---	---	---	---	---	---	---	3	15	18
81	---	2	---	3	---	2	---	4	1	2	---	---	2	---	1	3	13	17
84	---	1	1	1	---	---	---	3	---	1	---	2	1	---	---	4	6	10
87	1	---	---	1	---	---	---	---	1	2	---	---	1	---	---	3	3	6
93	---	---	---	1	---	---	---	---	---	---	---	---	---	---	---	---	1	1
96	---	---	---	---	---	---	---	1	---	---	---	---	---	---	---	---	1	1
Total	2	12	1	16	2	6	1	22	2	9	2	2	4	---	1	14	67	82
99	---	---	---	---	---	---	---	2	---	---	---	---	---	---	---	---	2	2
Grand total	13	61	14	84	19	71	9	137	2	17	5	2	15	---	19	74	375	468

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 55.—*Fractured tibia and fibula, United States veterans of the World War, rated 50-79 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]																		Total		
	10-19		20-29		30-39		40-49		50-59		60-69		70-79		80-89	100		Less than 10 per cent			
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Temporary	Permanent		Temporary	Permanent	Total [c]
15																1			1		1
18								1												1	1
24			1								1								2		2
Total			1					1			1					1			3	1	4
27						1														1	1
30				1						2										3	3
33		1						2		1				1				1		5	6
36								1	1									1	1	1	3
39																		1			1
42										1				2						3	3
45			1	1		1	1												2	2	4
48		1						2												3	3
Total		2	1	2		2	1	5	1	4				3				3	3	18	24
51			1					3		2									1	5	6
54				2		2		1	1	4		1	1						2	10	12
57	2			2				2	2	1		1		1				4	4	7	15
60		2		1		4												1		7	8
63		3		3		1		1	1	1		1			1				1	11	12
66	1	6		6		1		8		1		2		4		1		3	2	28	33
69				4		1						1		2		1		1	1	8	10
72	1			3	1	2	1	5		3						1			4	13	17
Total	4	11	1	21	1	11	1	20	4	12		6	1	7	1	3		9	15	89	113
75	1				1			3		1							1		2	5	7
78				1		2				3		1		1						8	8
81		1						1						2						4	4
84			1			1		1								3			4	2	6
87						1	1			1									1	2	3
90	1																		1		1
Total	2	1	1	1	1	4	1	5		5		1		3		3	1		8	21	29
99																1			1		1
Grand total	6	14	4	24	2	17	3	31	5	21	1	7	1	13	1	8	1	12	30	129	171

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 56.—*Fractured tibia and fibula, United States veterans of the World War, rated 100 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]																			Total		
	10–19		20–29		30–39		40–49		50–59		60–69		70–79		80–89		100		Less than 10 per cent			
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent		Temporary	Permanent	Total [c]
6			1				1	1									2	1		4	2	6
9	1			1				1	1	1				1			4	4		6	8	14
12								2									2	6		2	8	10
15	1		1					5										2		2	7	9
18	1	1	1	1				9	1									1	1	3	12	16
21	1	1	1		1			11									1	2		4	14	18
24		1				1		10	3								3	4		6	16	22
Total	4	3	4	2	1	1	1	39	5	1				1			12	20	1	27	67	95
27		1		2			1	18		1								4		1	26	27
30		2		2				37	1								4	7		5	48	53
33		1	1	3		1		37	1								3	4	1	5	46	52
36					1	2	1	24		2		1	1		1	1	6	9	1	10	39	50
39					1	2		19	1	1							2	6		4	28	32
42				2				27	1	1			1	1		1		6		2	38	40
45	2			2				22				1					2	2		4	27	31
48		1		3		1		22		2		1		1			8	3	1	8	34	43
Total	2	5	1	14	2	6	2	206	4	7		3	2	2	1	2	25	41	3	39	286	328
51		1	1	2				32	2	4	1	2					1	9	3	5	50	58
54		2	3	4		3	1	38	1	5		2			1	1	2	6	2	8	61	71
57		5	1	7	1	4		45	1	1		1	2			1		1	1	5	65	71
60	1	5	1	5	1	3		59	1	5		3	2			1	2			8	81	89
63		4	1	7	1	4		57	1	3	2	4	1			2	2		1	8	81	90
66		9	1	14		7	1	59	1	4		3	2	1		1	3			8	98	106
69	1	8		12		4		79	1	4		2		2		2	2	1	1	4	114	119
72		5	1	6	2	3		58	2	4		4	2				2	1		9	81	90
Total	2	39	9	57	5	28	2	427	10	30	3	21	9	3	1	8	14	18	8	55	631	694
75	1	1	1	4		2		39	3	7		3	1				5			11	56	67
78			1	4		3	1	29	1	2		6	1	3			4		1	8	47	56
81		2		2	1	4	1	19	2	3	1	1	1				3			9	31	40
84		2	1		1			11	1	3						1	2			5	17	22
87								7									4			4	7	11
90								2									2			2	2	4
93								1													1	1
96								3													3	3
Total	1	5	3	10	2	9	2	111	7	15	1	10	3	3		1	20		1	39	164	204
99						1		2													3	3
102								1													1	1
Total						1		3													4	4
Grand total	9	52	17	83	10	45	7	786	26	53	4	34	14	9	2	11	71	79	13	160	1,152	1,325

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 57.—*Fractured humerus, United States veterans of the World War, rated less than 10 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]								Total			Total [c]
	10–19		20–29		30–39	50–59	60–69	100	Less than 10 per cent	Temporary	Permanent	
	Temporary	Permanent	Temporary	Permanent	Temporary	Temporary	Temporary	Temporary				
3									21			21
6									4			4
9									2			2
12									3			3
15									3			3
21									4			4
24									3			3
Total									40			40
27		1							5		1	6
30									9			9
33						1			9	1		10
36				1					9		1	10
39									13			13
42									10			10
45		1			1				7	1	1	9
48									4			4
Total		2		1	1	1			66	2	3	71
51									6			6
54			1						5	1		6
57									6			6
60		1							6		1	7
63	1	1							4	1	1	6
66	2	1							6	2	1	9
69		1							6		1	7
72		2	1						2	1	2	5
Total	3	6	2						41	5	6	52
75							1		1	1		2
78		3							2		3	5
81		3							3		3	6
84		2		1				1	1	1	3	5
87									3			3
90		1							1		1	2
Total		9		1			1	1	11	2	10	23
Grand total	3	17	2	2	1	1	1	1	158	9	19	186

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 58.—*Fractured humerus, United States veterans of the World War, rated 10–29 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]																		Total			
	10–19		20–29		30–39		40–49		50–59		60–69		70–79		80–89		100					
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Less than 10 per cent	Temporary	Permanent	Total [c]
6		1	2																	2	1	3
9	4			2																4	2	6
12		2		1																	3	3
15	3	1	3																2	6	1	9
18	2		4	1															1	6	1	8
21	1	5		1		1													5	1	7	13
24		1	3				1			1	1								5	5	2	12
Total	10	10	12	5		1	1			1	1								13	24	17	54
27	3	1							1										5	4	1	10
30	5	2	7	4															9	12	6	27
33	14	2	10	2			1											1	8	25	5	38
36	9	4	4	5	1			1											11	14	10	35
39	14	6	3	10															7	17	16	40
42	10	2	5	10		2		2											7	15	16	38
45	8	14	9	4															11	17	18	46
48	5	14	4	8				2		1				1					12	9	26	47
Total	68	45	42	43	1	2	1	5	1	1				1				1	70	113	98	281
51	11	24	5	10		3						1							14	16	38	68
54	14	30	1	11		3		1	2	2							1		13	18	47	78
57	11	33	7	16	1	5		1								1			13	19	56	88
60	7	54	5	27		3		2	1							1		1	16	13	88	117
63	11	71	5	53		8		4		2				2					14	16	140	170
66	9	99	7	46	1	17		12		4		2							19	17	180	216
69	2	86	1	51		14	1	4	1	1		1		6					14	5	163	182
72	3	56	2	33	1	11		4		2		3		1	1	1			9	7	111	127
Total	68	453	33	247	3	64	1	28	4	11		7		9	1	3	1	1	112	111	823	1,046
75	2	25	4	33		9		3	1	1	1	1					1		8	9	72	89
78	7	22	2	21	1	1		3		3			1				1		4	12	50	66
81	5	11	3	15		5		3						2					3	8	36	47
84	1	10	1	10		1				2		1		1					1	2	25	28
87	2	10		1		4			1							1	1		2	4	16	22
90	1	2																	1	1	2	4
93		2		1															3		3	6
96		1		1																	2	2
Total	18	83	10	82	1	20		9	2	6	1	2	1	3		1	3		22	36	206	264
102				1																	1	1
Grand total	164	591	97	378	5	87	3	42	7	19	2	9	1	13	1	4	4	2	217	284	1,145	1,646

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the 6-year period of the study.

TABLE 59.—*Fractured humerus, United States veterans of the World War, rated 30–49 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]																	Total		
	10–19		20–29		30–39		40–49		50–59		60–69		70–79		80–89	100				
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Temporary	Less than 10 per cent	Temporary	Permanent	Total [c]
6					1	1												1	1	2
15						1	1											1	1	2
18					2													2		2
21					1													1		1
24				1		2		2									2		5	7
Total				1	4	4	1	2									2	5	7	14
27					3	1		1										3	2	5
30	1			1	2		1										1	4	1	6
33		1	1	1	3	4	3	1										7	7	14
36		1	1	1	1	3		3		1							2	2	9	13
39				1	1	4		7					1					2	12	14
42		2	3	4	1	3	2	4									4	6	13	23
45		2		1	3	4	2	4		1							3	5	12	20
48	2	1	1	4		7	1	7			1	1						5	20	25
Total	3	7	6	13	14	26	9	27		2	1	1	1				10	34	76	120
51		3	1	3	1	14		6			1	1						3	27	30
54		2	1	7	1	13	2	6		2		1					2	4	31	37
57		10	3	12	1	10	1	5	1	3			1	2			3	7	42	52
60	2	9		19	1	16		6		6		1			1		1	3	58	62
63	2	17		26	3	29		16		4		1		2		1	2	6	95	103
66		20	2	28	2	23		17	1	7		3		1	1	1	6	6	100	112
69	3	12	3	13		23		18		7		1			1	1	1	7	75	83
72		9	2	15	4	17		16		5		3					1	6	65	72
Total	7	82	12	123	13	145	3	90	2	34	1	11	1	5	3	3	16	42	493	551
75	1	10		8	1	13	1	7		7		2			1	1		4	48	52
78				10	3	5		4		6			1				1	4	25	30
81			1	6		3	1	5	1	2		2		1				3	19	22
84		2		4	1	1		4					1	1				2	12	14
87						3													3	3
90				2		1													3	3
93										1									1	1
Total	1	12	1	30	5	26	2	20	1	16		4	2	2	1	1	1	13	111	125
Grand total	11	101	19	167	36	201	15	139	3	52	2	16	4	7	4	4	29	94	687	810

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the 6-year period of the study.

TABLE 60.—*Fractured humerus, United States veterans of the World War, rated 50–79 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]																		Total		
	10–19		20–29		30–39		40–49		50–59		60–69		70–79		80–89	90–99	100	Less than 10 per cent			
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Permanent	Temporary		Temporary	Permanent	Total [c]
12									1	1									1	1	2
18									1										1		1
21													1	1					1	1	2
24									3		1	1							4	1	5
Total									5	1	1	1	1	1					7	3	10
27		1		1							1						1		2	2	4
30						2	1	1		1		1							1	5	6
33							1	1	2	1	1	1		4					4	7	11
36			1		2					2	1	1		1					4	4	8
39						2				2		2	1	1					1	7	8
42				2					1	3	1			1				1	2	6	9
45					1				1					3					2	3	5
48		1	2					2	3	3	1	5		1	1				6	13	19
Total		2	3	3	3	4	2	4	7	12	5	10	1	11	1		1	1	22	47	70
51		2			1	1				5	1	2		3	1	1			2	15	17
54	1	2	1	2		2		4		3	2	5	1	2	1				5	21	26
57		2		2		3	1	3	1	3		4		3				1	2	20	23
60		3	1	1		6				10		4		4	2	1	1		2	31	33
63	1	4	2	6		7		9		14		5		9	2				3	56	59
66	3	1	1	7		9		5	3	12		4	1	11	1	2			8	52	60
69		2		5		8	1	9		21	1	6		4	4		1		3	59	62
72		4		4		4		5		3		5	1	5	3		1		2	33	35
Total	5	20	5	27	1	40	2	35	4	71	4	35	3	41	14	4	3	1	27	287	315
75		2		2		3		3		6		5		5	3		2		2	29	31
78	1			3	1	1		3		9	1	7		6	2		1		4	31	35
81				3		3		1		1		7	2	4			1		3	19	22
84				1		1	1	1	1			2		2					2	7	9
87				1		1				1		1			1			1		5	6
90									1										1		1
93																1				1	1
Total	1	2		10	1	9	1	8	2	17	1	22	2	17	6	1	4	1	12	92	105
Grand total	6	24	8	40	5	53	5	47	18	101	11	68	7	70	21	5	8	3	68	429	500

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

Table 61.—*Fractured humerus, United States veterans of the World War, rated 80–99 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]												Total		
	10–19	20–29	40–49	50–59	60–69	70–79		80–89		90–99		100			
	Permanent	Permanent	Permanent	Permanent	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Temporary	Permanent	Total [c]
3									1					1	1
6									1		1			2	2
9									4					4	4
12									1					1	1
18									3		1			4	4
21									4		1			5	5
24									10					10	10
Total									24		3			27	27
27									2					2	2
30									4		3			7	7
33									6		2			8	8
36							1		6		2			9	9
39									7		2			9	9
42									8		2			10	10
45									14					14	14
48									13		3			16	16
Total							1		60		14			75	75
51			1						18		1			20	20
54							2		11		4			17	17
57									23		1			24	24
60	1						1		33		3			38	38
63			2		1		1		28		2			34	34
66			1		3		3		30		5			42	42
69		1					2	1	24		5		1	32	33
72				1	1	1	1		9		2		1	14	15
Total	1	1	4	1	5	1	10	1	176		23		2	221	223
75					1		1		14		1	2	2	17	19
78						1			1		1		1	2	3
81									7		1			8	8
84									2					2	2
87							1		1		2			4	4
90									1	1			1	1	2
Total					1	1	2		26	1	5	2	4	34	38
Grand total	1	1	4	1	6	2	13	1	286	1	45	2	6	357	363

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 62.—*Fractured humerus, United States veterans of the World War, rated 100 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b] 10–19 Temporary	10–19 Permanent	20–29 Temporary	20–29 Permanent	30–39 Temporary	30–39 Permanent	40–49 Temporary	40–49 Permanent	50–59 Temporary	50–59 Permanent	60–69 Temporary	60–69 Permanent	70–79 Temporary	70–79 Permanent	80–89 Temporary	80–89 Permanent	90–99 Permanent	100 Temporary	100 Permanent	Less than 10 per cent	Total Temporary	Total Permanent	Total [c]
6																		1			1		1
9		1						1								3		2	1		2	6	8
12			1		1	1								1		2			1		2	5	7
15									1							9		1			2	9	11
18			1	2				1	1					1		2	2	1			3	8	11
21						1							1	2		11	1		2		1	17	18
24				1	2									2		7				1	2	10	13
Total		1	2	3	3	2		2	2				1	6		34	3	5	4	1	13	55	69
27				1		1										3			3			8	8
30					1							1		2		9	1		3	1	1	16	18
33	1		2	1										2		8	1		4		3	16	19
36	1		1			1		1				1		1		9	1	1	2	1	3	16	20
39		1				1	1		2	1		1	1	1	1	12	1		3		5	21	26
42	1		1		1	2			1	4		1	1	2		7	2	1	3		6	21	27
45	1		2	1		1	1	2		1				2		9	1	2	2	1	6	19	26
48	1	3	2	1		2	1			1		1		3		14	1	1	3		5	29	34
Total	5	4	8	4	2	8	3	3	3	7		5	2	13	1	71	8	5	23	3	29	146	178
51	1		1	3				2		3		2		7		21	2	3	7		5	47	52
54		2	1	4	1	1		1		2		1	1	6	2	17	4		1	1	5	39	45
57	1	2	1	2		3		2	3	5		5		4		16				1	5	39	45
60		3	2	3		4		3		1		6	1	5		28	1				3	54	57
63		6	1	4	1	4	1	6		4		5	1	9	1	27	1	1		1	6	66	73
66		8		6		7		5		7		7		6		31	2	1		1	1	79	81
69	3	9	2	8		5	1	3		9	1	9		15		17	2	2		1	9	77	87
72		1		6		3		2		2		3		5	2	18	4	1			3	44	47
Total	5	31	8	36	2	27	2	24	3	33	1	38	3	57	5	175	16	8	8	5	37	445	487
75	2	3	1	3		2		1		3		3		7		9					3	31	34
78		1	1	1		2		4				3		3	1	7		2			4	21	25
81						1				1				1		3		2			2	6	8
84									1	1		2		1		3	1	1			2	8	10
87						1		1							1	1			1		1	4	5
90								1		1				2								4	4
96																1						1	1
Total	2	4	2	4		6		7	1	6		8		14	2	24	1	5	1		12	75	87
102																1						1	1
105		1																				1	1
Total		1														1						2	2
Grand total	12	41	20	47	7	43	5	36	9	46	1	51	6	90	8	305	28	23	36	9	91	723	823

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 63.—*Fractured ulna, United States veterans of the World War, rated 10–29 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]													Total		
	10–19		20–29		30–39		40–49		50–59	60–69	70–79	100	Less than 10 per cent			
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Temporary	Temporary	Temporary		Temporary	Permanent	Total [c]
3	2	1												2	1	3
6	2			1										2	1	3
9			4											4		4
12	2	1												2	1	3
15	2	1				1								2	2	4
18	1		1											2		2
21		1											2		1	3
24	2	1											2	2	1	5
Total	11	5	5	1		1							4	16	7	27
27	2												2	2		4
30	4	2	1										5	5	2	12
33	5	2		1			1						6	6	3	15
36	3	5	8	1									3	11	6	20
39	6	1	3	2	1								7	10	3	20
42	2	8	2	2									8	4	10	22
45	2	3	2	2									7	4	5	16
48	5	8	4	1	1								10	10	9	29
Total	29	29	20	9	2		1						48	52	38	138
51	5	13		5		1		1			1		8	6	20	34
54	7	9	2	7									2	9	16	27
57	2	14		13		1							11	2	28	41
60	4	28		7		2		2	1				15	4	40	59
63	11	32	1	19		5							10	12	56	78
66	2	37		12		3			2				10	2	54	76
69		41	3	17		3						1	9	4	61	74
72	2	24	1	11		3			3			1	7	4	41	52
Total	33	198	7	91		18		3	6		1	2	72	43	316	431
75	2	14		8	1			1					1	3	23	27
78	1	15	1	4		3							1	2	22	25
81	4	7		2		1							2	4	10	16
84	1	2		1										1	3	4
87	1	2		1										1	3	4
90		1											1		1	2
96		1													1	1
Total	9	42	1	16	1	4		1					5	11	63	79
Grand total	82	274	33	117	3	23	1	4	6		1	2	129	122	424	675

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 64.—*Fractured ulna, United States veterans of the World War, rated 30–49 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]													Total		
	10–19		20–29		30–39		40–49		50–59		60–69	70–79	Less than 10 per cent			
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Temporary		Temporary	Permanent	Total [c]
6					1									1		1
9								1							1	1
15							1							1		1
18						1	1							1	1	2
21					1								1	1		2
24						1									1	1
Total					2	2	2	1					1	4	3	8
27	1									1				1	1	2
30		1						1							2	2
33				1	1									1	1	2
36		1	1		1	2								2	3	5
39			1		3									4		4
42		1			1	8		1						1	10	11
45					2								1	2		3
48		1		1	2	1				1				2	4	6
Total	1	4	2	2	10	11		2		2			1	13	21	35
51	1	2		3		2		4					2	1	11	14
54		1	1	5	1	1		1			1	1		3	9	12
57		2				2		1		1			1		6	7
60	2	3	1	2	1	7		1	1				2	5	13	20
63		3		11		7		4		2					27	27
66		8	1	4				3		2			1	1	17	19
69	1	1		2		4		1					1	1	8	10
72		4		2		7		1					2		14	16
Total	4	24	3	29	2	30		16	1	5	1	1	9	11	105	125
75		5		6		3		3					1		17	18
78		4		5		3		5		2					19	19
81		1		3	1	1		1						1	6	7
84				1				1					1		2	3
87				1											1	1
Total		10		16	1	7		10		2			2	1	45	48
Grand total	5	38	5	47	15	50	2	29	1	9	1	1	13	29	174	216

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 65.—*Fractured radius, United States veterans of the World War, rated less than 10 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b] 10–19 Temporary	10–19 Permanent	20–29 Temporary	20–29 Permanent	30–39 Permanent	Total Less than 10 per cent	Total Temporary	Total Permanent	Total [c]
3T						17			17
6T						6			6
9T						2			2
12						4			4
15						5			5
18T						5			5
21						2			2
42						10			10
Total						51			51
27						8			8
30						10			10
33						2			2
36	1					4	1		5
39						8			8
42						9			9
45						8			8
48		1				8		1	9
Total	1	1				57	1	1	59
51		1				9		1	10
54						5			5
57		1				7		1	8
60						8			8
63		1		2		3		3	6
66	1					3	1		4
69						2			2
72	2	1				4	2	1	7
Total	3	4		2		41	3	6	50
75		2	1			2	1	2	5
78		1	1			2	1	1	4
81					1	1		1	2
84						1			1
93						2			2
Total		3	2		1	8	2	4	14
99				1				1	1
Grand total	4	8	2	3	1	157	6	12	175

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 66.—*Fractured radius, United States veterans of the World War, rated 10–29 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]															Total		
	10–19		20–29		30–39		40–49		50–59		60–69	70–79		100				
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Temporary	Permanent	Temporary	Less than 10 per cent	Temporary	Permanent	Total [c]
6	1	2	1													2	2	4
9	3	2	1													4	2	6
12	4															4		4
15	4		2	1											1	6	1	8
18	2			2											1	2	2	5
21	5	1	2						1						1	8	1	10
24	2			1											3	2	1	6
Total	21	5	6	4					1						6	28	9	43
27	3	2	2												6	5	2	13
30	2	4		1								1			6	3	5	14
33	3	2	2			1									10	5	3	18
36	5	8	1												9	6	8	23
39	8	5	1	2											5	9	7	21
42	4	7		7		1								1	2	5	15	22
45	6	3		4											6	6	7	19
48	3	4		4				1							11	3	9	23
Total	34	35	6	18		2		1				1		1	55	42	56	153
51	2	13		7	1			1							17	3	21	41
54	4	17	2	3								1			6	7	20	33
57	3	24	5	5		2		1					1		15	8	33	56
60	7	34	2	11		1				1					10	9	47	66
63	1	44	1	27		4						1			10	3	75	88
66	1	45	1	19	1	4		1	1	3	1			1	11	5	73	89
69	3	49	2	12		4		1	1		1				8	6	67	81
72	2	23		13	3	3		1		1					4	5	41	50
Total	23	249	13	97	5	18		5	2	5	2	2	1	1	81	46	377	504
75	3	17	2	12		1				3					2	5	33	40
78	1	9	1	9		1	1	1		1	1			1	5	4	22	31
81	1	1		4		1		3							5	1	9	15
84		4	1	3		1										1	8	9
87	1	3		2		2				1				1		2	8	10
90		1															1	1
93	1	1													1	1	1	3
96		1		1													2	2
Total	7	37	4	31		6	1	4		5	1			2	13	14	84	111
102			1													1		1
Grand total	85	326	30	150	5	26	1	10	3	10	3	3	1	4	155	131	526	812

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there are no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 67.—*Fractured radius, United States veterans of the World War, rated 30-49 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]												Total		
	10–19		20–29		30–39		40–49		50–59	60–69		Less than 10 per cent			
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Temporary	Permanent		Temporary	Permanent	Total [c]
15						1	1						1	1	2
18												1			1
Total						1	1					1	1	1	3
27					1								1		1
30						2	1						1	2	3
36						2		1						3	3
39	1							1					1	1	2
42									1					1	1
45		1	1			1	1					1	2	2	5
48		1	1	3	1	3							2	7	9
Total	1	2	2	3	2	8	2	2	1			1	7	16	24
51		2		2	1	2		1	2			1	1	9	11
54				2		5		1	1					9	9
57	1	5	1	1	1	2		1					3	12	12
60		4		5	1	1	2	1	1			1	3	12	16
63		4			1	6		1	2				1	13	14
66		1		5		5		4	1		1			17	17
69		6	1	11		3		2	3		2		1	27	28
72		4	1	1		4		1	1				1	11	12
Total	1	26	3	27	4	28	2	12	11		3	2	10	107	119
75		1		1		5								7	7
78		2		1		6		1		1			1	10	11
81				1			1	1					1	2	3
87									1					1	1
Total		3		3		11	1	2	1	1			2	20	22
Grand total	2	31	5	33	6	48	6	16	13	1	3	4	20	144	168

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 68.—*Fractured radius, United States veterans of the World War, rated 100 per cent disabled on first examination; showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]																	Total		
	10–19		20–29		30–39		40–49		50–59		60–69	70–79		80–89	100		Less than 10 per cent			
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Temporary	Permanent	Permanent	Temporary	Permanent		Temporary	Permanent	Total [c]
6		1																	1	1
9		1													1			1	1	2
12																	1			1
15	1																	1		1
18	1																	1		1
21				1	1											2	1	1	3	5
24																1	1		1	2
Total	2	2		1	1										1	3	3	4	6	13
27								1									1		1	2
30																1			1	1
33		1															1		1	2
36		2		1								1						1	3	4
39	1	1	1													1		2	2	4
42			1											1				1	1	2
45													1						1	1
48			1								1							1	1	2
Total	1	4	3	1				1			1	1	1	1		2	2	5	11	18
51		1		1						1				1	1		1	1	4	6
54		2	1				1	1	1	1		1				1		4	5	9
57			2	2														2	2	4
60		2		2				1			1								6	6
63		3	1	3	1	2			1	1	1		1			1		3	12	15
66		2		1		1				3		1						1	7	8
69			1			1		1		1								1	3	4
72		3				1				1	1			1					7	7
Total		13	5	9	1	5	1	3	2	8	3	2	1	2	1	2	1	12	46	59
75		1	1							1								1	2	3
78										1									1	1
81		1																	1	1
84		1			1			1										1	2	3
87						1				1									2	2
Total		3	1		1	1		1		3								2	8	10
Grand total	3	22	9	11	3	6	1	5	2	11	4	3	2	3	2	7	6	23	71	100

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 69.—*Fractured radius and ulna, United States veterans of the World War, rated less than 10 per cent disabled on first examination; showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]						Total			Total [c]
	10–19		20–29		30–39	80–89	Less than 10 per cent	Temporary	Permanent	
	Temporary	Permanent	Temporary	Permanent	Permanent	Permanent				
3							22			22
6							1			1
9							3			3
12							3			3
15							2			2
18							1			1
21							1			1
24							5			5
Total							38			38
27							3			3
30							6			6
33		1					10		1	11
36							15			15
39							13			13
42							21			21
45							7			7
48							16			16
Total		1					91		1	92
51							9			9
54							3			3
57		3					7		3	10
60		2					4		2	6
63				2			8		2	10
66		1			1		7		2	9
69		1	1				5	1	1	7
72	1						8	1		9
Total	1	7	1	2	1		51	2	10	63
75		2		1		1	3		4	7
78							3			3
81				1			2		1	3
84		1					2		1	3
87	1			1			2	1	1	4
90							1			1
96							1			1
Total	1	3		3		1	14	1	7	22
Grand total	2	11	1	5	1	1	194	3	18	215

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 70.—*Fractured radius and ulna. United States veterans of the World War, rated 10–29 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]															Total			
	10–19		20–29		30–39		40–49	50–59		60–69		70–79		90–99	100				
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Temporary	Less than 10 per cent	Temporary	Permanent	Total [c]
3	1	1	1														2	1	3
6	1	1	2	1													3	2	5
9	1	2		1													1	3	4
12	1	1															1	1	2
15	2	2		1													2	3	5
18	1	2														1	1	2	4
21	2	1	2	1												2	4	2	8
24	1	1	1	2												5	2	3	10
Total	10	11	6	6												8	16	17	41
27	3	1	1			1										6	4	2	12
30	4	1														5	4	1	10
33	6	4	3	2												5	9	6	20
36	6	4	5	5			2									6	11	11	28
39	5	5	2	3	1											14	8	8	30
42	3	4	2	5	2		1	1								8	8	10	26
45	7	6	2	5		1										7	9	12	28
48	9	12	1	3		1			1							11	10	17	38
Total	43	37	16	23	3	3	3	1	1							62	63	67	192
51	9	15	2	10	1		2		1					1		13	12	29	54
54	5	26	2	17												13	7	43	63
57	5	21	1	11		1			1							16	6	34	56
60	12	46	2	21		2			1				1			16	14	71	101
63	3	45	2	27		3					1					19	5	76	100
66	9	78	3	24	1	3	1		2		2					14	13	110	137
69	2	45	3	23		5	1	1								9	6	74	89
72	3	29	2	11		8			3				1			3	5	52	60
Total	48	305	17	144	2	22	4	1	8		3		2	1		103	68	489	660
75	1	32	2	15		2	4		3						1	7	4	56	67
78	6	14	2	6		4	3		1	1		1	1			3	10	29	42
81	2	12	2	9		1	1	1	1		1				1	1	6	25	32
84		6		4		2	1		1									14	14
87		7		1												1		8	9
90		2				1										5		3	8
93		2																2	2
96		1																1	1
Total	9	76	6	35		10	9	1	6	1	1	1	1		2	17	20	138	175
99	1															1	1		2
108				1														1	1
Total	1			1												1	1	1	3
Grand total	111	429	45	209	5	35	16	3	15	1	4	1	3	1	2	191	168	712	1,071

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 71.—*Fractured radius and ulna, United States veterans of the World War, rated 30–49 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]															Total		
	10–19		20–29		30–39		40–49		50–59		60–69		70–79		Less than 10 per cent [c]			
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent		Temporary	Permanent	Total [c]
6						2		1									3	3
21				1		1	1									1	2	3
24															1			1
Total				1		3	1	1							1	1	5	7
30		1		2				1			1					1	4	5
33				2	1										1	1	2	4
36		1			3	2	2	1								5	4	9
39	2				1		1	1								4	1	5
42		1		1		2		2									6	6
45		1			1	4	2	4							1	3	9	13
48		1	1	3		3		1		1					1	1	9	11
Total	2	5	1	8	6	11	5	10		1	1				3	15	35	53
51		1		3		3	2	2		2						2	11	13
54		3	1	3		2		4	1					1		2	13	15
57		2		6	1	4		4		1						1	17	18
60		5		7	1	7	1	1				1		1	1	2	22	25
63		4	2	5		8	1	6		2					1	3	25	29
66		6		10	2	9		11		3		1		1		2	41	43
69		2	1	10		11		7		1						1	31	32
72	1	3	1	6		9	1	5		1				1		3	25	28
Total	1	26	5	50	4	53	5	40	1	10		2		4	2	16	185	203
75				3		2		2		5		1		1			14	14
78		2		1		4		2	1	2		2	1			2	13	15
81		3			1	4		4		1						1	12	13
84		1							1	2						1	3	4
87		1						1		1							3	3
90												1					1	1
Total		7		4	1	10		9	2	11		4	1	1		4	46	50
Grand total	3	38	6	63	11	77	11	60	3	22	1	6	1	5	6	36	271	313

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

TABLE 72.—*Fractured radius and ulna, United States veterans of the World War, rated 50–79 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]																Total		
	10–19		20–29		30–39		40–49		50–59		60–69	70–79		80–89	100	Less than 10 per cent			
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Temporary	Permanent	Temporary	Temporary		Temporary	Permanent	Total [c]
3										1								1	1
6													1					1	1
15									1			1					2		2
18				1					1	1							1	2	3
24						1												1	1
Total				1		1			2	2		1	1				3	5	8
27				1							1							2	2
30	1								1								2		2
33													3					3	3
36	1									1			2				1	3	4
39											1					1		1	2
42						1				2	1		1			1		5	6
45				1		1	1			1	1						1	4	5
48				1						4	2		3					9	9
Total	2			3		2	1		1	8	6		8			2	4	27	33
51										3								3	3
54				2		1				1	4		4					12	12
57	1	1		1				2		2	3	1	6				2	15	17
60		2		1		2		2		5	2		6					20	20
63		1		2		3		2		7	4		7					26	26
66		3	1	5	1	4		4		15	6		6		1		3	43	46
69		2	1	3		4		4		5	3		3				1	24	25
72										8	4	1	1				1	13	14
Total	1	9	2	14	1	14		14		46	26	2	33		1		7	156	163
75		1		1		1		1		3	2		2	1			1	11	12
78		1			1			1	1	3			5				2	10	12
81				1				3		4			2					10	10
84						1					1							2	2
87										1	1		1					3	3
90										2								2	2
Total		2		2	1	2		5	1	13	4		10	1			3	38	41
Grand total	3	11	2	20	2	19	1	19	4	69	36	3	52	1	1	2	17	226	245

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

CORRECTION

Word "time," fourth line from bottom, page 543, to read "tissue."

TABLE 73.—*Fractured radius and ulna, United States veterans of the World War, rated 100 per cent disabled on first examination, showing interval elapsing between injury and last rating and degree of disability on last rating, as of January 1, 1926* [a]

Months (interval elapsing between injury and last rating)	Degree of impairment on last rating [b]																		Total			
	10-19		20-29		30-39		40-49		50-59		60-69	70-79		80-89		90-99	100		Less than 10 per cent			
	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Temporary	Permanent	Temporary	Permanent	Permanent	Temporary	Permanent		Temporary	Permanent	Total [c]
6																	1			1		1
9											1		1				1	1	1	1	3	5
15										2	3		1		1						7	7
18								1		2	1		5								9	9
21			1							2	2		4					1		1	9	10
24										4	1		1								6	6
Total			1					1		10	8		12		1		2	2	1	3	34	38
27			1			2				2			4							1	8	9
30										4			4				2	3		2	11	13
33									1	3			5					1		1	12	13
36					1				1	2	3		6					2	1	2	13	16
39				1				1		5	1		8				1	2		1	18	19
42				1	1					4	2		6				1	3		2	16	18
45			1	1						4	5		5				2	1	1	3	16	20
48		1		2		1		1		5	3		2		1			2			18	18
Total		1	2	5	2	3		2	2	29	17		40		1		6	14	2	12	112	126
51				1		1			1	9	3		3					3		1	20	21
54				1		4	1			7	5		10		3		1	4	1	2	34	37
57		2		1		2	1	1	1	10	5		7					1		2	29	31
60	1	1				1				6	4		6		3			1	1	1	22	24
63		3		1		2		2	1	9	5		10		1					1	33	34
66	1	2		1		1		1	1	7	7		15	1					1	3	34	38
69		3	1	3		3		2		9	7	1	15		1		1			3	43	46
72	1	4		1		1		1	1	9	3		10		2	1	1			3	32	35
Total	3	15	1	9		15	2	7	5	66	39	1	76	1	10	1	3	9	3	16	247	266
75				2				1		5	1		6			1					16	16
78		1		3				2	1	3	2		2							1	13	14
81								1		1	3		2								7	7
84		1								1	1	1	2							1	5	6
87											1										1	1
90													1								1	1
96													1								1	1
Total		2		5				4	1	10	8	1	14			1				2	44	46
Grand total	3	18	4	19	2	18	2	14	8	115	72	2	142	1	12	2	11	25	6	33	437	476

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau.
[b] Where the column is omitted there were no cases.
[c] Exclusive of patients who died during the six-year period of the study.

From the data in the above group of tables, Tables 74 and 75 have been prepared to show the number and per cent of cases which reached their stationary level after definite periods (Table 74), and the changes in percentages of impairment which occurred between the first and last examination (Table 75). It will be seen that the average period of disability (Table 75) is greatly in excess of that among industrial fractures. In this connection it must be borne in mind that a large number of the fractures under consideration were complicated by an osteomyelitis; furthermore, there was a nerve involvement in 14 per cent, which, together with the destruction of time, resulted in a prolonged or lasting impairment of function. Therefore, since the character of these fractures differ in a large measure from that of the industrial fracture, the final results are not comparable from a viewpoint of time.

TABLE 74.—*Fractures of the long bones, United States veterans of the World War, showing the number and percentage of cases which reached their stationary level after periods of 2, 3, 4, 5, or more years, as of January 1, 1926*

Bone	Total		Unclassified		Period									
					2 years		3 years		4 years		5 years		Over 5 years	
	Cases	Per cent	Cases	Per cent	Cases	Per cent	Cases	Per cent	Cases	Per cent	Cases	Per cent	Cases	Per cent
Femur	5, 138	100. 00	------	------	259	5. 04	435	8. 47	637	12. 40	1, 185	23. 06	2, 622	51. 03
Tibia	2, 289	100. 00	86	3. 76	118	5. 16	212	9. 26	266	11. 62	478	20. 88	1, 129	49. 32
Fibula	1, 243	100. 00	203	16. 33	89	7. 16	123	9. 90	153	12. 31	221	17. 78	454	36. 52
Tibia and fibula	4, 485	100. 00	23	. 51	226	5. 04	453	10. 10	562	12. 53	1, 027	22. 90	2, 194	48. 92
Humerus	4, 328	100. 00	------	------	214	4. 94	303	7. 00	492	11. 37	954	22. 04	2, 365	54. 64
Ulna	1, 169	100. 00	169	14. 46	60	5. 13	83	7. 10	129	11. 04	230	19. 67	498	42. 60
Radius	1, 356	100. 00	101	7. 45	110	8. 11	109	8. 04	145	10. 69	300	22. 12	591	43. 58
Radius and ulna	2, 340	100. 00	20	. 85	132	5. 64	185	7. 91	311	13. 29	538	22. 99	1, 154	49. 32
Total	22, 348	100. 00	602	2. 69	1, 208	5. 41	1, 903	8. 52	2, 695	12. 06	4, 933	22. 07	11, 007	49. 25

TABLE 75.—*Fractures of the long bones, United States veterans of the World War, showing the change in per cent of impairment on first examination by the United States Veterans' Bureau, and on the last examination prior to January 1, 1926*

Disability rating on first examination	Total		Disability rating on last examination											
			Less than 10		10–29		30–49		50–79		80–99		100	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Femur:														
Less than 10 per cent	119	100	94	78. 99	9	7. 56	3	2. 52	2	1. 68	3	2. 52	8	6. 72
10–29	1, 595	100	154	9. 66	1, 215	76. 18	127	7. 96	61	3. 82	9	. 56	29	1. 82
30–49	719	100	10	1. 39	228	31. 71	373	51. 88	94	13. 07	3	. 42	11	1. 53
50–79	493	100	6	1. 22	62	12. 58	100	20. 28	298	60. 45	8	1. 62	19	3. 85
80–99	100	100	------	-------	1	1. 00	2	2. 00	17	17. 00	77	77. 00	3	3. 00
100	2, 112	100	6	. 28	158	7. 48	121	5. 73	1, 199	56. 77	384	18. 18	244	11. 55
Total	5, 138	100	270	5. 25	1, 673	32. 56	726	14. 13	1, 671	32. 52	484	9. 42	314	6. 11
Amputations [a]	------	------	------	-------	1	-------	2	-------	1, 122	-------	443	-------	173	------
Tibia:														
Less than 10 per cent	215	100	192	89. 30	22	10. 23	------	-------	------	-------	------	-------	1	. 47
10–29	1, 474	100	369	25. 03	1, 023	69. 40	50	3. 39	16	1. 09	------	-------	16	1. 09
30–49	213	100	14	6. 57	108	50. 70	79	37. 09	11	5. 16	1	. 47	------	------
50–79	80	100	5	6. 25	33	41. 25	17	21. 25	23	28. 75	------	-------	2	2. 50
80–89	6	100	------	-------	------	-------	------	-------	2	33. 33	4	66. 67	------	------
100	301	100	18	5. 98	128	42. 52	50	16. 61	55	18. 27	10	3. 32	40	13. 29
Total	2, 289	100	598	26. 12	1, 314	57. 40	196	8. 56	107	4. 67	15	. 66	59	2. 58
Fibula:														
Less than 10 per cent	201	100	189	94. 03	11	5. 47	1	. 50	------	-------	------	-------	------	------
10–29	839	100	299	35. 64	508	60. 55	27	3. 22	3	. 36	------	-------	2	. 24
30–49	89	100	10	11. 24	47	52. 81	27	30. 34	5	5. 62	------	-------	------	------
50–79	28	100	3	10. 71	7	25. 00	10	35. 71	7	25. 00	------	-------	1	3. 57
80–99	2	100	------	-------	------	-------	------	-------	2	100. 00	------	-------	------	------
100	84	100	9	10. 71	43	51. 19	23	27. 38	3	3. 57	4	4. 76	2	2. 38
Total	1, 243	100	510	41. 03	616	49. 56	88	7. 08	20	1. 61	4	. 32	5	. 40

[a] Amputations are entered separately for convenience, but are included also among the fracture cases.

TABLE 75.—*Fractures of the long bones, United States veterans of the World War, showing the change in per cent of impairment on first examination by the United States Veterans' Bureau, and on the last examination prior to January 1, 1926*—Continued

Disability rating on first examination	Total		Disability rating on last examination											
			Less than 10		10–29		30–49		50–79		80–99		100	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Tibia and fibula:														
Less than 10 per cent	308	100	235	76.30	47	15.26	14	4.55	3	.97	1	.32	8	2.60
10–29	2,190	100	485	22.15	1,536	70.14	114	5.21	22	1.00			33	1.51
30–49	468	100	19	4.06	172	36.75	236	50.43	26	5.56			15	3.21
50–79	171	100	12	7.02	48	28.07	53	30.99	48	28.07	1	.58	9	5.26
80–99	23	100			4	17.39	7	30.43	5	21.74	6	26.09	1	4.35
100	1,325	100	13	.98	161	12.15	848	64.00	140	10.57	13	.98	150	11.32
Total	4,485	100	764	17.03	1,968	43.88	1,272	28.36	244	5.44	21	.47	216	4.82
Amputations							906		86		15		134	
Humerus:														
Less than 10 per cent	186	100	158	84.95	24	12.90	1	.54	2	1.08			1	.54
10–29	1,646	100	217	13.18	1,230	74.72	137	8.32	51	3.10	5	.30	6	.36
30–39	810	100	29	3.58	298	36.79	391	48.27	84	10.37	4	.49	4	.49
50–79	500	100	3	.60	78	15.60	110	22.00	275	55.00	26	5.20	8	1.60
80–99	363	100			2	.55	4	1.10	22	6.06	333	91.74	2	.55
100	823	100	9	1.09	120	14.58	91	11.06	203	24.67	341	41.43	59	7.17
Total	4,328	100	416	9.61	1,752	40.48	734	16.96	637	14.72	709	16.38	80	1.85
Amputations									55		602		31	
Radius and ulna:														
Less than 10 per cent	215	100	194	90.23	19	8.84	1	.47			1	.47		
10–29	1,071	100	191	17.83	794	74.14	56	5.23	27	2.52	1	.09	2	.19
30–49	313	100	6	1.92	110	35.14	159	50.80	38	12.14				
50–79	245	100	2	.82	36	14.69	41	16.73	164	66.94	1	.41	1	.41
80–89	20	100					1	5.00	13	65.00	6	30.00		
100	476	100	6	1.26	44	9.24	36	7.56	339	71.22	15	3.15	36	7.56
Total	2,340	100	399	17.05	1,003	42.86	294	12.56	581	24.83	24	1.03	39	1.67
Amputations									383		16		22	
Radius:														
Less than 10 per cent	175	100	157	89.71	17	9.71	1	.57						
10–29	812	100	155	19.09	591	72.78	42	5.17	20	2.46			4	.49
30–49	168	100	4	2.38	71	42.26	76	45.24	17	10.12				
50–79	99	100	2	2.02	21	21.21	24	24.24	52	52.53				
80–99	2										2	100.00		
100	100	100	6	6.00	45	45.00	15	15.00	22	22.00	3	3.00	9	9.00
Total	1,356	100	324	23.89	745	54.94	158	11.65	111	8.19	5	.37	13	.96
Ulna:														
Less than 10 per cent	109	100	98	89.91	11	10.09								
10–29	675	100	129	19.11	506	74.96	31	4.59	7	1.04			2	.30
30–49	216	100	13	6.02	95	43.98	96	44.44	12	5.56				
50–79	75	100	3	4.00	14	18.67	22	29.33	32	42.67	3	4.00	1	1.33
80–99	2	100					1	50.00	1	50.00				
100	92	100	4	4.35	38	41.30	19	20.65	24	26.09	2	2.17	5	5.43
Total	1,169	100	247	21.13	664	56.80	169	14.46	76	6.50	5	.43	8	.68

The changed ratings, as shown in Table 75, may be arranged in three groups: (1) Diminished ratings, which indicate an improvement; (2) stationary ratings; (3) increased ratings, which indicate not only that there was no improvement in the cases concerned but also that they had assumed a more serious character. This grouping is as follows:

Long bones	Total cases	Ratings					
		Diminished		Stationary		Increased	
		Cases	Per cent	Cases	Per cent	Cases	Per cent
Femur	5, 138	2, 448	47. 7	2, 301	44. 8	389	7. 5
Tibia and fibula	4, 485	1, 980	44. 2	2, 211	49. 3	294	6. 5
Tibia	2, 289	809	35. 3	1, 361	59. 5	119	5. 2
Fibula	1, 243	457	36. 8	736	59. 2	50	4. 0
Humerus	4, 428	1, 527	35. 3	2, 446	56. 5	355	8. 2
Radius and ulna	2, 340	840	35. 9	1, 353	57. 8	147	6. 3
Radius	1, 356	368	27. 1	887	65. 4	101	7. 5
Ulna	1, 169	365	31. 2	737	63. 1	67	5. 7
Total	22, 348	8, 794	39. 4	12, 032	53. 8	1, 522	6. 8

The following data have been arranged to show the percentage of improvement, as the result of fractured long bones among the United States veterans of the World War, on the first and on the last examination prior to January 1, 1926. As may be seen, the tabular matter summarizes the data of Tables 40 to 73, and of Table 75.

Bone	Number	Examination	Rating less than 10		Rating 10–29		Rating 30–49		Rating 50–79		Rating 80–99		Rating 100	
			Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Femur	5, 138	First	119	2. 32	1, 595	31. 04	719	13. 98	493	9. 59	100	1. 95	2, 112	41. 11
		Last	270	5. 25	1, 673	32. 56	726	14. 13	1, 671	32. 52	484	9. 42	314	6. 11
Tibia	2, 289	First	215	9. 39	1, 474	64. 39	213	9. 31	80	3. 49	6	. 26	301	13. 15
		Last	598	26. 12	1, 314	57. 41	196	8. 56	107	4. 57	15	. 66	59	2. 58
Fibula	1, 243	First	201	16. 17	839	67. 50	89	7. 16	28	2. 25	2	. 16	84	6. 76
		Last	510	41. 03	616	49. 56	88	7. 08	20	1. 61	4	. 32	5	. 40
Tibia and fibula.	4, 485	First	308	6. 87	2, 190	48. 83	468	10. 43	171	3. 81	23	. 51	1, 325	29. 54
		Last	764	17. 03	1, 968	43. 88	1, 272	28. 36	244	5. 44	21	. 48	216	4. 81
Humerus	4, 328	First	186	4. 30	1, 646	38. 03	810	18. 72	500	11. 55	363	8. 39	823	19. 02
		Last	416	9. 61	1, 752	40. 48	734	16. 96	637	14. 72	709	16. 38	80	1. 85
Ulna	1, 169	First	109	9. 32	675	57. 74	216	18. 48	75	6. 42	2	. 17	92	7. 87
		Last	247	21. 13	664	56. 80	169	14. 46	76	6. 50	5	. 43	8	. 68
Radius	1, 356	First	175	12. 91	812	59. 88	168	12. 39	99	7. 30	2	. 15	100	7. 37
		Last	324	23. 89	745	54. 94	158	11. 65	111	8. 18	5	. 37	13	. 97
Radius and ulna.	2, 340	First	215	9. 19	1, 071	45. 77	313	13. 38	245	10. 47	20	. 85	476	20. 34
		Last	399	17. 05	1, 003	42. 86	294	12. 56	581	24. 83	24	1. 03	39	1. 67
Total	22, 348	First	1, 528	6. 84	10, 302	46. 10	2, 996	13. 41	1, 691	7. 57	518	2. 32	5, 313	23. 77
		Last	3, 528	15. 75	9, 735	43. 56	3, 637	16. 28	3, 447	15. 42	1, 267	5. 67	734	3. 28

Finally, a group of 4,647 cases of fractured femur was studied with the view of showing the relationship of changes in ratings to the time when the injured veterans had their first examinations. This study is given in Table 76. This table shows that, of the 4,647 cases in which the femur alone was fractured, 3,352 cases, or 72 per cent, were examined and rated within 12 months after injury. Of these cases, 1,227, or 37 per cent, were given a disability rating of 10–29, and 1,239, or 37 per cent, were rated totally disabled. Of the 1,227 cases rated 29 on first examination, there was a change in rating of only 11

TABLE 76.—*A study of 4,647 single femur fractures among the World War veterans, showing the changes in ratings by six-month intervals from the Veterans Bureau's first examination after injury, as of January 1, 1926* [a] [b]

Status of all cases by 6-month intervals

CASES RATED ON FIRST EXAMINATION 12 MONTHS, OR PRIOR THERETO, AFTER INJURY

Rating	Cases	18 months after injury: 0	10-29	30-49	50-79	80-99	100	24 months after injury: 0	10-29	30-49	50-79	80-99	100	30 months after injury: 0	10-29	30-49	50-79	80-99	100	36 months after injury: 0	10-29	30-49	50-79	80-99	100	42 months after injury: 0	10-29	30-49	50-79	80-99	100
0	96	95	1					94	1				1	91	3		1		1	88	4		2		2	85	6		1		4
10-29	1,227	7	1,178	6			36	11	1,159	11	5		41	28	1,134	18	13	1	33	41	1,118	21	13	2	32	46	1,109	28	16	3	25
30-49	407		8	389	1		9	1	26	362	3		15	2	42	346	8		9	3	58	323	9		14	3	67	312	12		13
50-79	314		4	1	301	1	7		16	3	286	1	8		24	11	269	1	9		29	15	259	1	10		34	16	252	2	10
80-99	69					68	1					69					1	68					2	66	1				2	66	1
100	1,239		25	21	234	57	902		35	33	552	133	486	2	50	41	686	173	287	3	62	41	713	197	223	5	64	45	710	204	211
Total	3,352	102	1,216	417	536	126	955	106	1,237	409	846	203	551	123	1,253	416	978	243	339	135	1,271	400	998	266	282	139	1,280	401	993	275	264

Rating	48 months after injury: 0	10-29	30-49	50-79	80-99	100	54 months after injury: 0	10-29	30-49	50-79	80-99	100	60 months after injury: 0	10-29	30-49	50-79	80-99	100	66 months after injury: 0	10-29	30-49	50-79	80-99	100	72 months after injury: 0	10-29	30-49	50-79	80-99	100
0	83	8				5	81	8		1	1	5	82	8		1	2	3	82	8		1	2	3	82	6	1	2	2	3
10-29	52	1,087	30	19	4	35	78	1,050	36	26	4	33	86	1,037	43	25	5	31	97	1,017	47	32	4	30	105	993	60	34	5	30
30-49	5	81	297	15		9	6	111	263	20	1	6	7	125	244	25	1	5	7	139	224	29	1	7	8	144	219	30	1	5
50-79		35	19	246	2	12	2	36	22	242	2	10	3	38	25	233	2	13	3	37	29	230	1	14	3	39	28	227	2	15
80-99				2	66	1		1		2	65	1		1		2	65	1		1		3	64	1		1		3	64	1
100	4	69	53	724	214	175	4	78	52	730	230	145	4	84	50	746	240	115	4	87	51	760	242	95	4	89	49	763	242	92
Total	144	1,280	399	1,006	286	237	171	1,284	373	1,021	303	200	182	1,293	362	1,032	315	168	193	1,289	351	1,055	314	150	202	1,272	357	1,059	316	146

Rating	78 months after injury: 0	10-29	30-49	50-79	80-99	100	84 months after injury: 0	10-29	30-49	50-79	80-99	100	90 months after injury: 0	10-29	30-49	50-79	80-99	100	96 months after injury: 0	10-29	30-49	50-79	80-99	100	102 months after injury: 0	10-29	30-49	50-79	80-99	100
0	81	6	1	2	2	4	81	5	1	2	2	5	81	6	1	1	2	5	81	6	1	1	2	5	81	6	1	1	2	5
10-29	116	979	65	36	7	24	116	976	69	36	7	23	117	974	69	36	7	24	117	974	70	36	7	23	117	974	70	36	7	23
30-49	9	152	208	33	2	3	8	155	205	34	2	3	8	155	206	34	2	2	8	155	207	34	1	2	8	155	207	34	1	2
50-79	3	41	31	226	3	10	3	41	32	225	3	10	3	41	32	224	3	11	3	41	32	224	3	11	3	41	32	224	3	11
80-99				4	63	2				5	62	2				5	62	2				5	62	2				5	62	2
100	4	92	51	773	246	73	4	90	52	772	245	76	4	90	52	774	243	76	4	90	52	777	246	70	4	90	52	777	246	70
Total	213	1,270	356	1,074	323	116	212	1,267	359	1,074	321	119	213	1,266	360	1,074	319	120	213	1,266	362	1,077	321	113	213	1,266	362	1,077	321	113

CASES RATED ON FIRST EXAMINATION 18 MONTHS AFTER INJURY

Rating	Cases	18 months after injury: 0	10-29	30-49	50-79	80-99	100	24 months after injury: 0	10-29	30-49	50-79	80-99	100	30 months after injury: 0	10-29	30-49	50-79	80-99	100	36 months after injury: 0	10-29	30-49	50-79	80-99	100	42 months after injury: 0	10-29	30-49	50-79	80-99	100
0	14							13	1					13	1					13	1					12	1				1
10-29	166								161		1		4		159	2	1		4	5	151	4	2		4	5	145	9	3		4
30-49	145								3	136			6	1	7	128	1		8	1	8	126	6		4	2	10	124	7		2
50-79	105									2	97		6		2	5	88	2	8		2	4	86	3	10		3	4	88	3	7
80-99	33											33			1	1		31				1	1	30	1			1	1	29	2
100	315								10	12	83	31	179		15	18	124	47	111		17	23	138	54	83		18	23	142	57	75
Total	778							13	175	150	181	64	195	14	185	154	214	80	131	19	179	158	233	87	102	19	177	161	241	89	91

Rating	48 months after injury: 0	10-29	30-49	50-79	80-99	100	54 months after injury: 0	10-29	30-49	50-79	80-99	100	60 months after injury: 0	10-29	30-49	50-79	80-99	100	66 months after injury: 0	10-29	30-49	50-79	80-99	100	72 months after injury: 0	10-29	30-49	50-79	80-99	100
0	12	1				1	10	3				1	10	3				1	10	3				1	10	3				
10-29	6	144	8	4		4	7	138	15	5			9	133	14	6		4	10	129	16	8		3	12	124	19	7		1
30-49	1	15	115	8		6	1	15	115	8		7	1	20	108	11		5	1	24	103	13		2	2	23	99	17		4
50-79		3	6	84	3	9		4	9	87	3	4		4	11	84	3	3		6	15	76	3	5		7	16	73	6	4
80-99			1	1	28	3				2	25	4				2	27	3			2	6	25				2	6	21	2
100	1	20	19	140	62	73		23	19	146	70	57		22	18	154	71	51		24	25	155	71	46		26	24	158	74	38
Total	20	183	149	237	93	96	18	183	158	248	98	73	20	182	151	257	101	67	21	186	161	258	99	57	24	183	160	261	101	49

Rating	78 months after injury: 0	10-29	30-49	50-79	80-99	100	84 months after injury: 0	10-29	30-49	50-79	80-99	100	90 months after injury: 0	10-29	30-49	50-79	80-99	100	96 months after injury: 0	10-29	30-49	50-79	80-99	100	102 months after injury: 0	10-29	30-49	50-79	80-99	100
0	10	3					10	3					10	3					10	3				1	10	3				1
10-29	15	118	22	9		2	15	117	22	10		2	15	117	22	10		2	14	114	25	11		2	14	114	25	11		2
30-49	1	37	71	31		4	1	38	72	20	1	4	1	36	73	30	1	4	1	36	72	28	1	7	1	36	72	28	1	7
50-79		9	20	68	6	3		9	19	68	5	4		9	19	68	5	4		9	17	71	4	4		9	17	71	4	4
80-99			2	5	24	2			2	5	24	2		1	2	5	24	2		1	2	5	24	1		1	2	5	24	1
100		27	27	164	76	21		26	28	163	77	21		26	28	163	78	20		26	29	163	78	19		26	29	163	78	19
Total	26	195	142	277	106	32	26	194	143	275	107	33	26	192	144	276	108	32	25	189	145	278	107	34	25	189	145	278	107	34

CASES RATED ON FIRST EXAMINATION 24 MONTHS AFTER INJURY

Rating	Cases	18 months after injury: 0	10-29	30-49	50-79	80-99	100	24 months after injury: 0	10-29	30-49	50-79	80-99	100	30 months after injury: 0	10-29	30-49	50-79	80-99	100	36 months after injury: 0	10-29	30-49	50-79	80-99	100	42 months after injury: 0	10-29	30-49	50-79	80-99	100
0	4													4						4						4					
10-29	57													1	55		1			1	50		2		4	2	50		3		2
30-49	61														1	55			5		2	53	1		5		6	49	2		4
50-79	86														2	2	79		3		3	6	68	1	8		4	8	69	2	3
80-99	8																	8					1	7					1	7	
100	128														4	10	27	4	83		5	14	34	10	65		5	14	40	13	56
Total	344													5	62	67	107	12	91	5	60	73	106	18	82	6	65	71	115	22	65

Rating	48 months after injury: 0	10-29	30-49	50-79	80-99	100	54 months after injury: 0	10-29	30-49	50-79	80-99	100	60 months after injury: 0	10-29	30-49	50-79	80-99	100	66 months after injury: 0	10-29	30-49	50-79	80-99	100	72 months after injury: 0	10-29	30-49	50-79	80-99	100
0	4						4						4						4						4					
10-29	3	48		3		2	4	46		1			4	47		3		1	3	47	1	3		2	3	45	2	3		2
30-49		8	47	2		4		6	47	4		2	1	1	44	6		2	1	10	42	5		4	1	9	41	6		5
50-79		3	10	67	1	5		6	9	70	2	2		1	11	68	1	3		3	16	63	1	3		1	18	62	2	3
80-99				1	7					4	2	1				2	8					1	8					3	5	
100		6	14	46	13	49		6	15	49	20	44		16	16	53	13	39		4	17	61	13	32		5	20	62	14	26
Total	7	65	71	119	22	60	8	64	71	128	24	49	9	65	71	132	22	45	8	64	76	133	22	41	8	60	81	136	23	36

Rating	78 months after injury: 0	10-29	30-49	50-79	80-99	100	84 months after injury: 0	10-29	30-49	50-79	80-99	100	90 months after injury: 0	10-29	30-49	50-79	80-99	100	96 months after injury: 0	10-29	30-49	50-79	80-99	100	102 months after injury: 0	10-29	30-49	50-79	80-99	100
0	4						4						4						4						4					
10-29	3	45	3	3		1	3	45	3	3		1	3	44	4	3		1	4	42	6	3			4	42	6	3		
30-49		9	41	8	2	3		9	40	10	2	2		10	40	10	2	2		10	38	11	2			10	38	11	2	
50-79		2	25	48	4	7		2	24	49	4	7		1	24	49	4	7		2	24	51	4	2		2	24	51	4	2
80-99				2	6					2	6					2	6					2	6	5				2	6	5
100		7	24	61	14	22		7	24	62	14	21		7	24	62	14	21		9	24	60	14	21		9	24	61	14	20
Total	7	63	93	122	26	33	7	63	91	126	26	31	7	62	92	126	26	31	8	63	92	127	26	28	8	63	92	128	26	27

CASES RATED ON FIRST EXAMINATION 30 MONTHS AFTER INJURY

Rating	Cases	18 months after injury: 0	10-29	30-49	50-79	80-99	100	24 months after injury: 0	10-29	30-49	50-79	80-99	100	30 months after injury: 0	10-29	30-49	50-79	80-99	100	36 months after injury: 0	10-29	30-49	50-79	80-99	100	42 months after injury: 0	10-29	30-49	50-79	80-99	100
0	2																			2						2					
10-29	15																				11				3		10		3		2
30-49	13																					12	1					11	1		
50-79	19																						18	1	1			17	2	1	
80-99	3																							3						1	2
100	38																				1		8	2	27	1		2	6	2	27
Total	90																			2	12	12	27	6	31	3	10	30	12	4	31

Rating	48 months after injury: 0	10-29	30-49	50-79	80-99	100	54 months after injury: 0	10-29	30-49	50-79	80-99	100	60 months after injury: 0	10-29	30-49	50-79	80-99	100	66 months after injury: 0	10-29	30-49	50-79	80-99	100	72 months after injury: 0	10-29	30-49	50-79	80-99	100
0	2						2						2						2						2					
10-29		10	1	3		1		10	1	2		2	1	9	2	4			1	8	1	5			1	8	1	4		
30-49		1	10	1				2	9					2	10	1				2	9	1				3	9	1		
50-79				18	1	1			2	16	1	1			1	11	5	1			2	17	1				2	14	1	
80-99				3	1					3	1					2	1					2	1					2	2	
100	1	2	2	8	3	21	1	2	3	11	2	19	1	3	3	12	4	15	1	3	3	12	3	15	1	3	4	12	5	13
Total	3	13	13	33	5	23	3	14	15	32	4	22	4	14	16	30	10	16	4	13	15	37	5	16	4	14	16	33	8	15

Rating	78 months after injury: 0	10-29	30-49	50-79	80-99	100	84 months after injury: 0	10-29	30-49	50-79	80-99	100	90 months after injury: 0	10-29	30-49	50-79	80-99	100	96 months after injury: 0	10-29	30-49	50-79	80-99	100	102 months after injury: 0	10-29	30-49	50-79	80-99	100
0	1						1						1						1						1					
10-29	2	5	2	4		1	2	6	4	3		2	2	6	4	3		2	2	8	2	3			2	8	2	3		
30-49		3	8	1				3	7	1				3	7	1				3	8	1				3	8	1		1
50-79			2	14	1	2		2	1	13	1	2		2	1	13	1	2		2	1	16	1	1		2	1	16	1	1
80-99				2	2					2	1					2	1					2	1					2	1	
100	1	4	4	18	7	6	1	3	4	18	7	6	1	3	4	18	7	6	1	1	4	19	7	6	1	1	4	19	7	5
Total	4	12	16	39	10	9	4	14	16	37	9	10	4	14	16	37	9	10	4	14	15	41	9	7	4	14	15	41	9	7

CASES RATED ON FIRST EXAMINATION 36 MONTHS AFTER INJURY

Rating	Cases	18 months after injury: 0	10-29	30-49	50-79	80-99	100	24 months after injury: 0	10-29	30-49	50-79	80-99	100	30 months after injury: 0	10-29	30-49	50-79	80-99	100	36 months after injury: 0	10-29	30-49	50-79	80-99	100	42 months after injury: 0	10-29	30-49	50-79	80-99	100
1	1																									1					
10-29	6																										6				
30-49	7																											7			
50-79	3																												2		1
100	49																												3		46
Total	66																									1	6	7	5		47

Rating	48 months after injury: 0	10-29	30-49	50-79	80-99	100	54 months after injury: 0	10-29	30-49	50-79	80-99	100	60 months after injury: 0	10-29	30-49	50-79	80-99	100	66 months after injury: 0	10-29	30-49	50-79	80-99	100	72 months after injury: 0	10-29	30-49	50-79	80-99	100
1	1						1						1						1						1					
10-29		6						6						6						6						6				
30-49			5			2			4			3			5			2			7						7			
50-79				2		1				2		1				2		1				3						3		
100		1		6		42		1		11	2	35		1		12	3	33		1		17	3	28		1		20	2	26
Total	1	7	5	8		45	1	7	4	13	2	39	1	7	5	14	3	36	1	7	7	20	3	28	1	7	7	23	2	26

Rating	78 months after injury: 0	10-29	30-49	50-79	80-99	100	84 months after injury: 0	10-29	30-49	50-79	80-99	100	90 months after injury: 0	10-29	30-49	50-79	80-99	100	96 months after injury: 0	10-29	30-49	50-79	80-99	100	102 months after injury: 0	10-29	30-49	50-79	80-99	100
1	1						1						1						1						1					
10-29		6						6						5	1					3	3					3	3			
30-49			7						7						6	1					6	1					6	1		
50-79				3						3						3						3						3		
100			2	18	5	24			2	18	5	24			2	19	4	24			2	19	4	24			2	19	4	24
Total	1	6	9	21	5	24	1	6	9	21	5	24	1	5	9	23	4	24	1	3	11	23	4	24	1	3	11	23	4	24

CASES RATED ON FIRST EXAMINATION 42 MONTHS AFTER INJURY

Rating	Cases	18–42 months after injury	48 months after injury: 0	10-29	30-49	50-79	80-99	100	54 months after injury: 0	10-29	30-49	50-79	80-99	100	60 months after injury: 0	10-29	30-49	50-79	80-99	100	66 months after injury: 0	10-29	30-49	50-79	80-99	100	72 months after injury: 0	10-29	30-49	50-79	80-99	100
10-29	1			1						1						1						1						1				
30-49	2				2						2						2						2						2			
50-79	2					2						1		1				1		1				1		1				1		1
100	2							2			1	1					1	1						1		1		1	1			
Total	7			1	2	2		2		1	3	2		1		1	3	2		1		1	2	2		2		2	3	1		1

Rating	78 months after injury: 0	10-29	30-49	50-79	80-99	100	84 months after injury: 0	10-29	30-49	50-79	80-99	100	90 months after injury: 0	10-29	30-49	50-79	80-99	100	96 months after injury: 0	10-29	30-49	50-79	80-99	100	102 months after injury: 0	10-29	30-49	50-79	80-99	100
10-29		1						1						1						1						1				
30-49			2						2						2						2						2			
50-79				1		1				1		1				1		1				1		1				1		1
100			1	1					1	1						2						2						2		
Total		1	3	2		1		1	3	2		1		1	2	3		1		1	2	3		1		1	2	3		1

CASES RATED ON FIRST EXAMINATION 48 MONTHS AFTER INJURY

Rating	Cases	18–48 months after injury	54 months after injury: 0	10-29	30-49	50-79	80-99	100	60 months after injury: 0	10-29	30-49	50-79	80-99	100	66 months after injury: 0	10-29	30-49	50-79	80-99	100	72 months after injury: 0	10-29	30-49	50-79	80-99	100
10-29	3			3						2	1					2	1					2	1			
30-49	2				2						2						2						2			
50-79	2					2						2						2						2		
Total	7			3	2	2				2	3	2				2	3	2				2	3	2		

Rating	78 months after injury: 0	10-29	30-49	50-79	80-99	100	84 months after injury: 0	10-29	30-49	50-79	80-99	100	90 months after injury: 0	10-29	30-49	50-79	80-99	100	96 months after injury: 0	10-29	30-49	50-79	80-99	100	102 months after injury: 0	10-29	30-49	50-79	80-99	100
10-29		2	1					2	1					2	1					2	1					2	1			
30-49			1	1					1	1					1	1					1	1					1	1		
50-79				2						2						2						2						2		
Total		2	2	3				2	2	3				2	2	3				2	2	3				2	2	3		

CASES RATED ON FIRST EXAMINATION 54 MONTHS AFTER INJURY

Rating	Cases	18–48 months after injury	54 months: 50-79	60 months: 50-79	66 months: 50-79	72 months: 50-79	78 months: 50-79	84 months: 50-79	90 months: 50-79	96 months: 50-79	102 months: 50-79
50-79	3		3	3	3	3	3	3	3	3	3

[a] Source of information: Coordination Service, Evaluation Division, U. S. Veterans' Bureau

[b] Where the initial rating was made prior to 1 year from injury to first examination, the subsequent 12-month rating was used. Cases included under zero are disallowed or terminated because of disabilities rated less than 10 per cent.

per cent over a period of four years. Of the 1,239 cases rated totally disabled on first examination, 337 cases, or 27 per cent, improved in the first 6 months; in the following 6 months, 416, or 34 per cent, improved; 199, or 16 per cent, were improved 30 months after injury. Among the totally disabled cases originally examined by the United States Veterans' Bureau within a year after injury, a reexamination 5 years after injury revealed that 1,124, or 91 per cent, showed definite signs of improvement; only 70, or 5 per cent, showed no improvement. It will be noted that 778, or 17 per cent, were first examined by the United States Veterans' Bureau 18 months after injury, and 344, or 7 per cent, were rated first 24 months, and 173, or 4 per cent, were rated first 30 months or more after injury.

Table 76 shows further that there is a significant decrease in the degree of disability in those cases which came to the bureau 12 months after injury, as compared with those who applied for relief at a later date. This degree of improvement is well illustrated in the totally disabled group by a comparison of those cases included under the claimants' first examination 12 months after injury with those applying for relief for the first time 18 months or 24 months after injury. This comparison shows also that at the end of 4 years the cases received within 12 months revealed an improvement of 86 per cent; those received 18 months, 77 per cent; those received after 24 months, 62 per cent; those received 30 months, 45 per cent; while of those received after 36 months, only 14 per cent improved. The same condition also exists in the degree of disability obtaining three years after injury.

The conclusion that the earlier the application for relief the more rapid the degree of improvement is apparently given greater emphasis through a study of conditions existing at the end of eight years. For instance, of those patients reporting within two years 95 per cent had improved at the end of eight years; among those patients who delayed as much as three years in reporting for relief the number of improved cases dropped to 51 per cent. This decrease in per cent of cases is particularly significant because five years had elapsed in those cases received three years after injury, which period was sufficient to accomplish practically the maximum improvement in the cases reporting for relief earlier.

REFERENCES

(1) Letter from the Director, United States Veterans' Bureau, Washington, May 26, 1926, to Lieut. Col. F. W. Weed, M. C. Subject: Statistical data. On file, Historical Division, S. G. O.

SECTION II

ORTHOPEDIC SURGERY

CHAPTER I

ORGANIZATION

DIVISION OF MILITARY ORTHOPEDIC SURGERY

At a meeting of the American Orthopedic Association held in Washington in May, 1916, it was voted that, in consideration of the possible contingencies which might arise in this country from war in Europe, there should be appointed a preparedness committee, whose duty it would be to consider the needs and equipment of orthopedic hospitals should such be required in any future emergency. The president of the association appointed this committee, which formulated a standardization of special hospital supplies and equipment, and reported to the association at its meeting in Pittsburgh, in May, 1917. At this meeting it was voted that the association should offer the services of its members to the Government in any way most acceptable, and suggested that aid in orthopedic methods of examination, treatment, and instruction of conditions affecting the soldier in training, would be a practicable activity.

On July 2, 1917, the resolutions passed by the association were presented to the Surgeon General by a committee, and the suggestions embodied therein were accepted by him. He requested that the committee prepare a brief of directions for distribution to surgeons in camps to serve as a basis of instruction and examination in matters of orthopedic interest. This brief [1] comprised instruction in regard to the foot and footwear, and to the affections of joints, spine, etc., and was intended to serve as a guide for the standardization of orthopedic work in military usage.

In accordance with the plan of organization which provided for representation of the different branches of medicine and surgery in the Surgeon General's Office,[2] on July 25, 1917, a reserve officer was detailed to take charge of the part of the work that included orthopedic surgery and physical reconstruction.[3]

It was evident at once that a large amount of work would be necessary at the time of the incoming drafts in camps, and as reports from abroad were showing the rapid development of the need of orthopedic surgery among the disabled soldiers, and as it was also evident that there would be need of preparation on a large scale for the care of our soldiers when they should be returned to this country, plans were at once formulated to provide for the work in the Surgeon General's Office. An orthopedic advisory council was formed, composed mainly of ex-presidents of the American Orthopedic Association and of

those representing the orthopedic section of the American Medical Association, and these representatives were invited to serve in an advisory capacity.[4]

The first meeting was held on August 2, 1917. It was decided at this meeting that a letter should be sent to all orthopedic surgeons, stating that this council had been formed, and requesting that all questions of an orthopedic nature be submitted to and go through the chairman of the council, and that a circular letter be sent to all of the men who were practicing orthopedic surgery, for the purpose of obtaining data on their qualifications and their availability for service. In view of the large number who would be called upon for orthopedic service during this war, it was the opinion that instruction should be instituted in the universities and hospitals to give additional training to those who should take up the work. It was suggested, also, that a circular bulletin be sent at intervals to all who were interested in orthopedic surgery, to give information in reference to the activities of this division. Accordingly, a bulletin announcing the formation and purposes of the council was sent to all the surgeons in the country who were known to be interested in orthopedic surgery.[5]

The Surgeon General decided, after several conferences with the officer then in charge of orthopedic surgery, to create a division of orthopedic surgery; to plan for the proper personnel both in France and in the United States; to arrange for the necessary hospital equipment overseas, which would provide for the special care of the soldier as soon after his injury as possible; for the development of the orthopedic reconstruction in the United States, and for the work of orthopedic surgery in the Army.[a] He directed that a report be prepared which would serve as a basis for the development of such a division, and which would embody the outlines of its work.[6]

It was evident at this period that the immediate needs, in addition to the work already outlined for the cantonments, were: To provide for the care of future orthopedic cases in France by the establishment of hospitals especially equipped and supplied with the special personnel; to provide for the demand for a large increase of available surgeons who could aid in carrying on this increased work, both in France and in the United States; to provide hospital facilities for the orthopedic reconstruction of disabled soldiers returning to the United States; and at the same time to provide the means for the industrial reeducation of these same men, to fit them for return to civil life, and arrange for their installation; to provide a large corps of specially trained masseurs to treat the joint and muscle conditions and deformities such as were being met with in the other countries, and to organize these workers into some official position.

The Surgeon General directed the division of orthopedic surgery to provide the proper personnel, both for France and for the United States, to arrange for the necessary hospital equipment overseas, and to develop plans for orthopedic reconstruction in the United States, including the orthopedic work in the cantonments.

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[a] For details of the organization and work of the division of military orthopedic surgery, see Vol. I, Chap. XVII, p. 424.

After the original personnel of the division of military orthopedic surgery was more or less automatically supplied and determined by the enrolling of the available trained orthopedic surgeons, it was quite apparent that this force must be considerably augmented as the demands upon its numbers increased. It was clear that the source of this supply must be found among the younger general surgeons and a number of the many young practitioners who had already obtained acceptable training along surgical lines.

The policy of the orthopedic division was to depend entirely upon recommendations or personal applications for the first contact with the candidate. When such recommendation or application was received, the person recommended or submitting the application was immediately reserved to orthopedic service if not commissioned, or if commissioned and not reserved for other service. A personal questionnaire was then sent to him.

Upon the return of the questionnaire properly filled, an effort was made to verify the contained statement of the experience and qualifications of the applicant and to decide as to his desirability and his availability. Applicants who appeared desirable and available were then either transferred to the orthopedic service, if already commissioned, or were advised as to seeking a commission before assignment. As soon as possible these officers were assigned to classes in the various courses in order to receive special instruction in both the military and surgical aspects of their future work before assuming their camp duties.

In these early days it was evident that the number of available orthopedic surgeons would prove inadequate and that it would be necessary to give special instruction to some of the younger surgeons who desired to enter the division of orthopedic surgery, in order to train them as assistants to orthopedic surgeons.

Early in September, 1917, arrangements were made with the postgraduate department of Harvard University [7] and with the New York Post Graduate Medical School and Hospital [8] to establish a course of instruction, and a definite syllabus of this instruction was prepared with the advice of the orthopedic advisory council. On October 15, arrangement was made to extend the course of instruction to include Philadelphia.[7]

Early in November, 1917, with the experience gained in the university courses, a meeting of the council and teachers was held in Washington and a standardized course of instruction determined upon, this schedule was used in all courses of instruction.

Through the cooperation of orthopedic surgeons of New York, another course was arranged for that city, instruction to begin November 1.[9] As many of the men from the far South and Southwest were applying for the opportunity of entering this division and for instruction, it was decided that in order to avoid the expense of long transportation, similar courses should be established in different parts of the country. Accordingly, arrangement was made to organize a course in Oklahoma City, to begin December 1.[10] The facilities at the Army Medical School, Washington, were utilized for special orthopedic instruction.[11]

In the fall of 1917, an orthopedic service was established at the Walter Reed General Hospital, Washington, and the use of the wards and clinical

material was offered in connection with the proposed course established officially through the approval of the Surgeon General.[11] The first class under this arrangement entered upon the course on November 12, 1917, and the establishment of the course as a part of the Army Medical School was announced.[12]

A medical officer who had had unusual technical training was detailed for service in the Army Medical School as teacher of applied mechanics, apparatus, and plaster, and was also given charge of the establishment of the school. Experts connected with the Surgeon General's Office gave instruction in their special branches. Later, other schools were established, following the same plan and schedule of instruction, and in the summer of 1918, courses were being given in Boston, New York, Philadelphia, Washington, Camp Greenleaf, Chicago, Oklahoma City, and Los Angeles. In all 691 officers passed through the different schools.[13]

By an arrangement with the Bureau of Medicine and Surgery, Navy Department, the courses of instruction in orthopedic surgery were made available for naval medical officers.[14]

TRAINING WITH THE BRITISH

The return of the British wounded to England had made it evident that over 50 per cent of the serious battle casualties represented chronic conditions of the extremities—bones, joints, muscles, and nerves—and special centers had been prepared for their reception. By the spring of 1917, it was impossible to man these special surgical centers with British surgeons who had had orthopedic training because of the demand on the English medical profession for service on the various battle fronts. It was for this reason that Maj. Gen. Sir Robert Jones, through the British Medical Department, asked for American orthopedic surgeons.[15] [a]

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[a] The following statement made by Maj. Gen. Sir Robert Jones, R.A.M.C., portrays the orthopedic situation in England and, in addition, expresses an appreciation of the activities of the American orthopedic surgeons who were supplied by our Government for duty in British orthopedic hospitals:

"The Great War made so extensive and sudden a demand upon medical overseas service that we were faced with a serious shortage of young medical men at home. This shortage became more and more acute as time passed, and was experienced in every department of surgery. Were it not for the great ability and vision of our Director General (Sir Alfred Keogh) events would have proved much more tragic than they did. As it was, fractures and wounds which had been carefully treated abroad lacked an adequate continuity in their treatment on arrival here—for, owing to the character of our struggle and the sudden and ever growing demand for beds, a fear naturally arose that a stasis would seriously dislocate military operations. Under such conditions a choice of evils favored the rapid emptying of our beds. In the same spirit that the soldiers sacrificed their lives, a further sacrifice was demanded of our wounded.

"In 1916 we were ordered to start an orthopedic hospital for military cases in Liverpool, but at that time so short of hospitals were we all over the country that only 250 beds could be afforded to the so-called chronic or orthopedic cases. At that time it was not fully realized that an ideal orthopedic hospital was primarily intended to prevent the occurrence of disability and deformity, which in so large a proportion of cases were the results of hurried evacuation and inefficient treatment. The wards were immediately filled with a ghastly array of derelicts. In spite of the fact that we were seriously handicapped for want of staff, the experiment proved so successful that I was practically given a free hand to increase our beds in Liverpool and start similar establishments in other centers. In a few months we had increased our bed accommodation from 250 to nearly 20,000. By degrees the orthopedic hospital was found in London, Leeds, Edinburgh, Aberdeen, Glasgow, Newcastle, Manchester, Bristol, Newport, Cardiff, Dublin, Belfast, and other towns. Instead of dealing merely with cases which resulted from want of continuity in treatment, and which were hopelessly crippled, we received many directly from abroad. This was the opportunity which was needed in order to stem the tide of deformity. Our aim in forming an orthopedic center was to procure:

"(1) A staff of surgeons who had had previous experience of the principles and practice of orthopedic surgery, operative, manipulative, and educational.

"(2) Men who though not specializing in orthopedic surgery were interested in it, and only needed experience to fit them to take charge of wards as new centers were formed.

"(3) Still younger men, who were ultimately to go abroad where a training in the elements of orthopedic work would be to their great advantage.

The first group sent over consisted of 20 selected men.[16] They were surgeons who had had a considerable amount of experience in civil orthopedic surgery and some experience in industrial surgery. On their arrival in England they were shown the work being done in the British war hospitals. A few weeks were spent in learning the types of disabilities that were met as the sequelæ of war wounds and the methods of treatment that had proven efficacious. Then one or two senior medical officers and several junior officers were assigned to the various hospitals in Great Britain, the principal centers being Shepard's Bush, Oxford, Manchester, Edinburgh, Glasgow, Aberdeen, and Cardiff.

The Americans were at once put in charge of wards or of services and were made responsible to the British surgeons in charge.[16] The increased staff made possible more intensive study of the cases and closer supervision of the treatment. It also made possible better coordination of the various measures used in restoration of function. One man made or helped make the diagnosis, performed or assisted at the operation if one were required, and had charge of the subsequent treatment, which usually consisted of massage, hydrotherapy, electrotherapy, exercises, and work in some curative vocation. The vocations found useful were fish-net making, basket work, wood turning, jig-saw work, cabinet making, and carpentry. Forestry and farming also were employed.

The types of cases referred to this section were those requiring restoration of function to muscles, tendons, and joints; and as the muscle, joint, and tendon changes formed an important part of the results of nerve injuries, nerve lesions were included, as were also malunited and ununited fractures. As the work developed one surgeon not only took part in, but was made responsible for the ordering of the entire treatment of a given patient, so that there was as perfect coordination of the treatment as possible from the time the patient was received up to the time of his discharge.[16]

"(4) The center would further consist of a series of auxiliary departments, each under an expert in the particular methods of treatment under his direction, such as departments for electricity massage, muscle-reeducation, hydrology, and gymnastic drill.

"Every center contained on its staff, in addition to specialists, a well-known surgeon, a neurologist, and a physician and consultations were of weekly occurrence in which every member participated.

"A great feature of these centers was the curative workshops. They acted directly and indirectly on the welfare and recovery of the patient—directly as a curative agent when the work done gave exercise to the disabled limb, the work being employed as an agent in restoring coordinate movements; indirectly in the psychological effect produced by the stimulus of work. King Manuel, representing the British Red Cross and St. John of Jerusalem, was our tower of strength in this department.

"Before the development of these hospitals was in any way complete we were hard pressed to the point of despair for the want of young orthopedic surgeons. It was anathema to keep any young surgeon in the country. The authorities on this point were adamant. Their views were, that as it had become necessary for surgeons with families to go abroad, no excuse could hold good for the retention in this country of young men, no matter how expert. 'Could not the older men be trained to do orthopedic work,' we were asked. At last permission was given that we could retain 12 young surgeons, and we were promised that under no circumstances would they be sent abroad. This was a great gain; but 12 men could not do justice to so vast a problem as that which confronted us, and the work was sorely handicapped. It was at this moment that your great nation came to our assistance. Sir John Goodwin placed before the American authorities a statement of our difficulties, and they promised us help. I shall never forget the thrill of joy I experienced when there arrived in Liverpool five young orthopedic surgeons placed at our disposal by the American Government for the period of the war. They were an extraordinarily fine body of men, keen, enthusiastic, and well trained. These units were distributed amongst the various centers and were given charge of wards. It is impossible to speak too highly of their loyalty, discipline, and devotion to duty. There sprang up immediately a bond of fraternity between them and their English colleagues, and the relationship was maintained throughout. The American Government wisely decided that their young surgeons on their way to the war area should spend a few weeks in the English orthopedic centers in order to gain experience. This arrangement was of distinct benefit to both nations. We often had over a hundred American surgeons working in this country at one time.

"I should like to pay a tribute of gratitude to America for the splendid service rendered by these young men. They came to us in our extremity; they filled a gap which seriously threatened to sterilize our reconstructive efforts, and they filled it with distinction and success."

Into such organizations new groups of young medical men were taken on their arrival from America, trained for three months or more, and then sent to the American hospitals in France.[16] It was a graduate school of the most thorough and practical type and made possible the training of men in a short time to do efficient work not only for the British Army but also for the American Army when they were transferred.

The special points learned were the best means for restoring function to stiffened joints, or, if joints were destroyed, the positions of choice for ankylosis of the various joints as shoulders, elbows, wrists, hips, knees, and ankles. Vocation plays a part in the choice and at first this was not considered. The value and methods of tendon transplanation were carefully worked out. The diagnosis of nerve lesions was studied and the treatment of nerve lesions greatly advanced. Methods of treatment of simple and compound fractures were well learned in the orthopedic centers because the patients were kept there until late results were determined.

Another smaller group of American orthopedic surgeons went overseas with the first American base hospital unit which had been organized under the American Red Cross and hastily commissioned in the United States.[16] They were sent at the request of the British Medical Department to take over, in connection with other American base hospitals, certain British general hospitals in France receiving wounded direct from casualty clearing stations on the Flanders front.

These men were endeavoring to show that orthopedic surgery had its contribution to make to acute general surgery; deformity, if it was to be prevented, must be recognized as potential deformity in the early stages of wound healing. The contribution was not a conspicuous one but nevertheless a real and a considerable one. They learned the wonderful toleration and resistance of the synovial membrane; how to overcome infection; danger of marking time in war wounds; new methods of immobilization. They did not forget their plaster technique but they appreciated its limitations. They were able to work out a system of splinting which, taking the best that the British experience had demonstrated and adding certain American types which measured up to this standard, has stood the hard test of the war and enormously simplified our treatment of fractures and joint injuries.

STANDARDIZATION OF SPLINTS

In the supply of proper splints to our armies and hospitals overseas throughout the military activities the development of the idea of proper splinting for the wounded did not come suddenly as a completed system but rather gradually, being built up by experience. Early in August, 1917, a number of the senior medical officers of the American Expeditionary Forces saw the advisability of fixing some standards for splints and appliances and surgical dressings for the American Expeditionary Forces. It was realized that the great majority of American surgeons coming to France would have had little or no experience with the treatment of battle casualties and that, unless

something was done to put the best kind of a system in force at the beginning, our Army would have to start, at the cost of both life and limb to our men, and gradually build up, through recognition of mistakes, to the point attained by the British and French after three years of war experience. A board of selected medical officers was appointed to study the question and make suitable recommendations thereon. This board was commonly known as the splint board. There were two such boards, the first of which was called into existence by a special order issued August 20, 1917, an extract of which follows: [17]

> A board of medical officers is hereby appointed to meet at these headquarters, at the call of the president thereof, for the purpose of investigating and reporting upon the advisability of standardizing certain appliances to be used by the Medical Department, and upon completion of this duty will return to their proper stations. The board will be guided by instructions from the chief surgeon.

This board was made up of six surgeons who were especially fitted by their past experience and insight into the requirements of the situation to undertake this work. One of its first acts was to recommend to the chief surgeon, A. E. F., that it be empowered to choose not only splints but also the surgical dressings and accessories necessary to a complete but limited equipment for the medical units of the American Expeditionary Forces. Further, that it be instructed to produce a small book, suitably bound, that would contain all the information on the character of these supplies for the Medical Department, as well as a simple, definite outline as to how to use them—a manual, in fact, for the use of all medical officers.[18] The chief surgeon approved these recommendations and the board instituted a definite plan of action.

MANUAL OF SPLINTS AND APPLIANCES, FIRST EDITION

Meanwhile the manuscript and drawings for the "splint manual" [19] were accepted finally and the board adjourned, making the following recommendations: (*a*) That the manuscript of the manual be submitted to the chief surgeon for his approval and adoption; (*b*) that the American Red Cross be requested to have 25,000 copies printed for distribution to all medical officers of the United States Army; (*c*) that the American Red Cross take immediate steps to start the manufacture of splints, so that when our troops became engaged and suffered casualties there would be the necessary appliances on hand to take care of the fractures according to the rules laid down in the manual; (*d*) that all questions relative to changes in this equipment, or in the methods advised for its use, be referred to the board for its action in order to prevent useless duplication or impractical ideas gaining a foothold.

By way of comment on the celerity with which the labors of the board were accomplished: The order calling the board into existence was issued on August 20, 1917; [17] the date of the commanding general's signed approval of the manuscript of the manual was September 9, 1917; [18] the first copies of the first edition were delivered to the supply depots of the American Expeditionary Forces six weeks later. The board had also chosen a set of surgical dressings, and had made an agreement with the American Red Cross for the manufacture of the standard splint accessories.

The following extracts from the introduction to the Manual of Splints and Appliances illustrates the attitude of the board toward their problems:

The board was unanimous in its opinion that the splints and appliances officially adopted by the American Army should possess the following qualifications: (1) Efficiency and correct mechanical principles. (2) Simplicity of design and low cost of construction, so that sufficient quantities may be always available. (3) Transportability, in order that an efficient splint may be applied at the front and remain in situ until the patient reaches the more or less permanent base hospital, and, if occasion demands or the surgeon elects, may even be expected to make possible an entirely satisfactory end result without change of the type of splint.

The Medical Department has no desire to dictate the exact line of treatment which shall be employed in the base hospitals. It is the desire, on the contrary, to encourage ingenuity in devising better methods for the treatment of these bone and joint injuries, which comprise so large a proportion of the battle casualties. The board is convinced, however, after a careful review of existing methods in the armies of the Allies and enemies, and a personal experience in the active treatment of these lesions in the present war, that the simple apparatus recommended may be employed with entire satisfaction as to the end results, and without any great degree of previous training.

The board believes that with the three types of wire-ring traction and counter-pressure fixation splints embodying the Thomas principle, the Jones "cock-up," "crab" wrist splint, the long interrupted Liston splint, with adjustable foot piece, an anterior thigh and leg splint, Hodgen type, the Cabot posterior wire splint, the wire-ladder splint material, light splint wood, and plaster of Paris bandages and Bradford frames, treatment of all bone and joint battle casualties may be efficiently carried out at the front and, if necessary, in base hospitals.

Holding this belief they have been influenced in thus restricting their recommendations to the above types of splints and splint material, by a consideration of the following advantages which their universal use would secure: (1) Possibility of quick manufacture and ease of distribution, thereby making available large numbers of splints of unit construction. (2) The combination of traction and fixation in the same apparatus, thereby favoring the comfort of the patient and avoiding the necessity of accessory adjustment. (3) Universality of type and simplicity of mechanical principle, thereby insuring quick familiarity with their uses and efficient application by the surgeon.

* * * * * * *

It will at once be obvious that this manual does not aim to be a complete treatise on the treatment of this class of lesions. Its purpose is to put into the hands of the military surgeon a practical, time-saving guide, in which the text has been made completely subservient to graphic illustration.

MANUFACTURE OF THE STANDARD SPLINTS AND ACCESSORIES

The American Red Cross undertook the manufacture of the various surgical supplies that the splint board had adopted as standard for the American Army,[19] until such time as the Army could take over the work and carry it out without assistance from outside agencies, because at that time there was no organization in the American Expeditionary Forces that had either the time or the personnel to undertake such a venture, while the Red Cross had at its disposal both of these commodities.

A bureau was established in the building occupied by the American Red Cross where the samples which were submitted were examined and compared with the models. It proved that unless definite standards absolutely were insisted upon, remarkable variations would appear in the output. Contracts were given to eight shops situated about Paris; however, owing to the difficulty

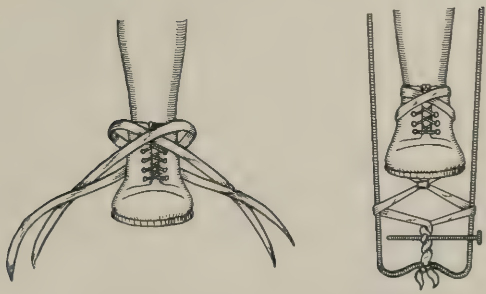

FIG. 1.—The Poliquen hitch. This and Figures 2 and 3 illustrate three practical methods of applying traction to a fractured lower extremity over the shoe. These methods are simple and can be executed after sufficient practice in the dark. The adjustable traction strap is a special device for this purpose. The Poliquen hitch and the Collins hitch are made with muslin bandages

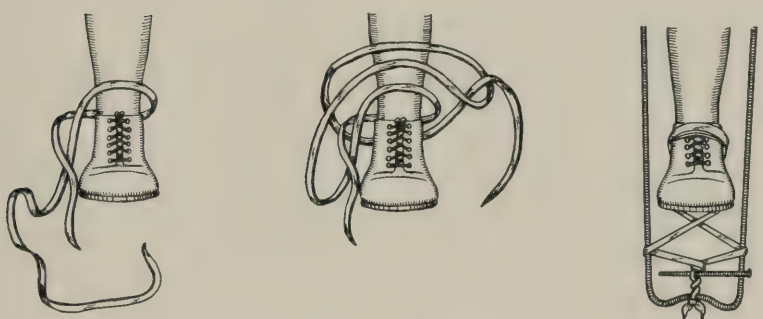

FIG. 2.—The Collins hitch

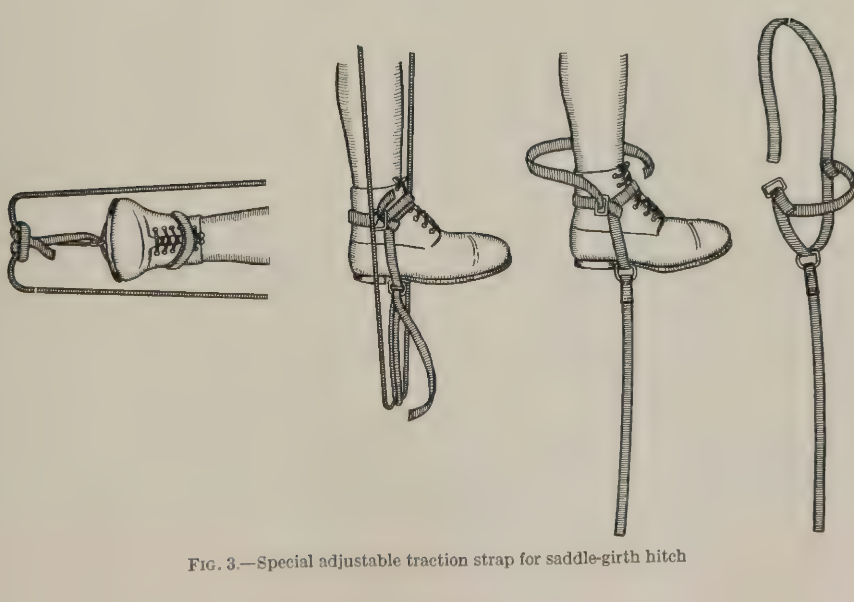

FIG. 3.—Special adjustable traction strap for saddle-girth hitch

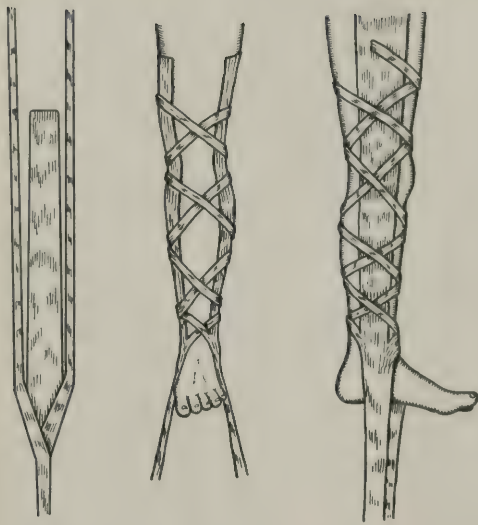

FIG. 4.—Adhesive plaster traction. Method of cutting and folding traction adhesive strips; anterior view of application to leg; lateral view of application to leg; the lateral band 1½ inches wide, the spiral strap ½ inch wide

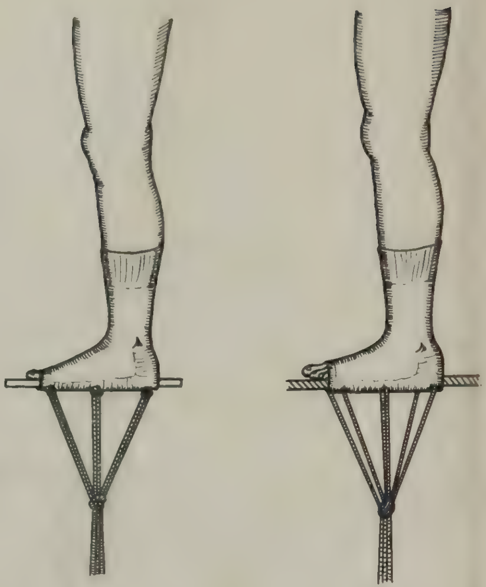

FIG. 5.—Stocking traction. Light-weight sock cut off at toes glued to lower leg, ankle, and dorsum of foot; piece of splint wood or ladder splint material passed between sock and sole of foot; traction by means of cords tied through sock and splint material

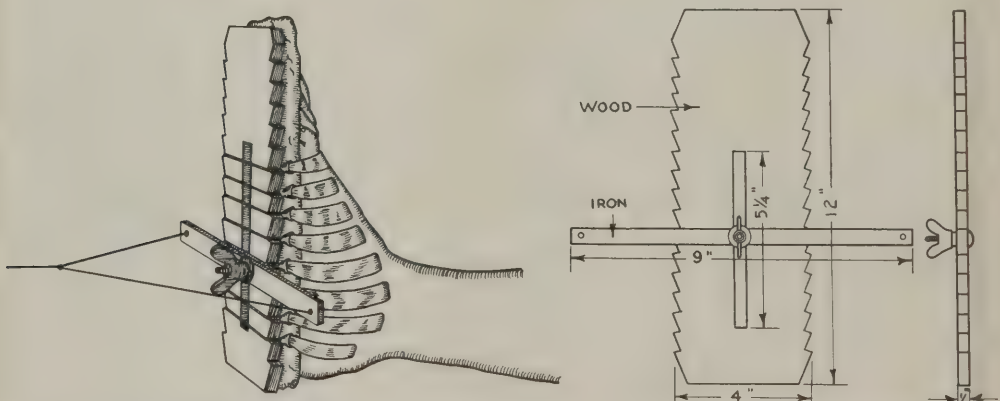

FIG. 6.—Sinclair skate. A board cut as pictured and attached to the foot by adhesive plaster or glued strips. These strips may be extended up the leg as far as the position of the wounds permits. The position of the foot as to flexion or extension, or as to rotation inward or outward, is obtained by adjusting the screw which slides up and down in slot The inversion or eversion of the foot is obtained by adjusting the length of the cords as they run to the extension cord

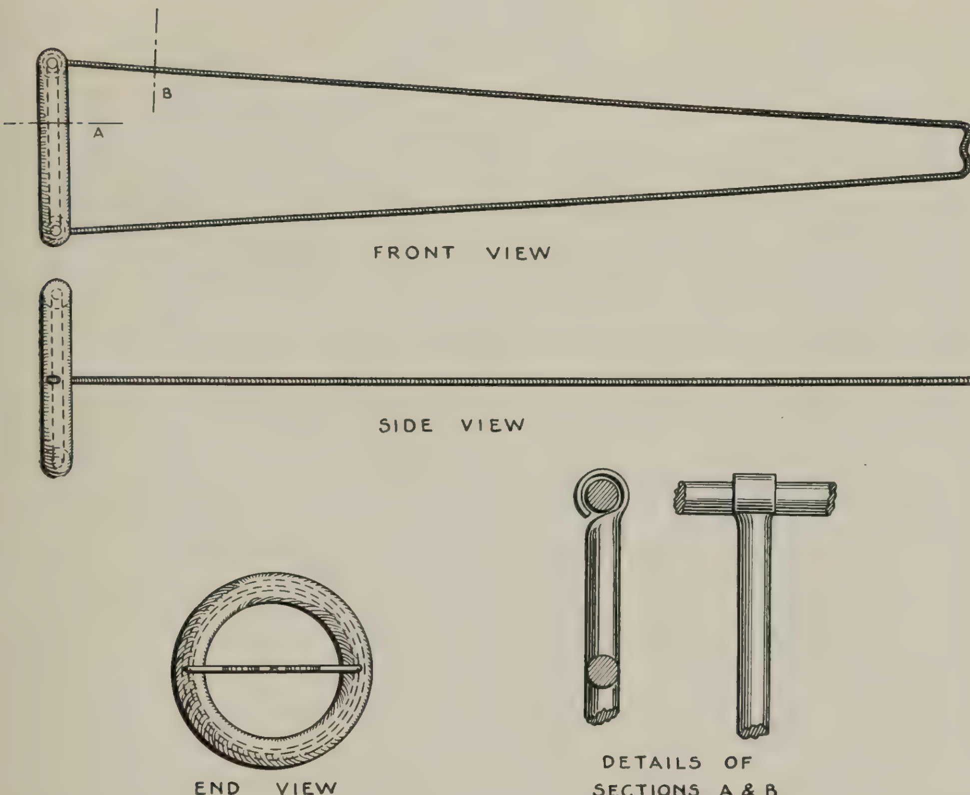

Fig. 7.—Mechanical drawing of Thomas traction arm splint. For bed treatment chiefly. Uses: Injuries to the shoulder joint; to the shaft of the humerus; to the elbow joint; to the forearm

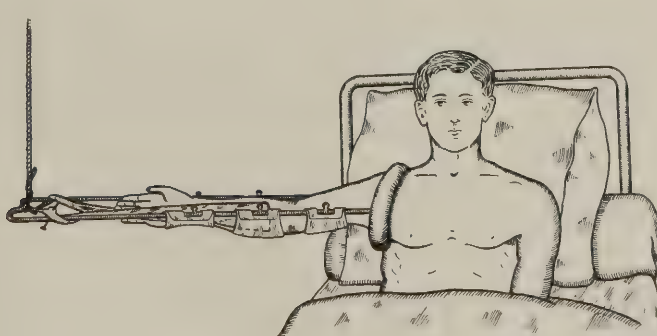

Fig. 8.—Thomas traction arm splint; applied for bed treatment. Rods are in horizontal plane and arm is resting on slings which are held with clips. By tightening or loosening these slings the position of the fragments of the bone may be modified. Traction is obtained by tightening the extension strips, which are attached to the end of the splint. Note the position of the hand with two-thirds full supination

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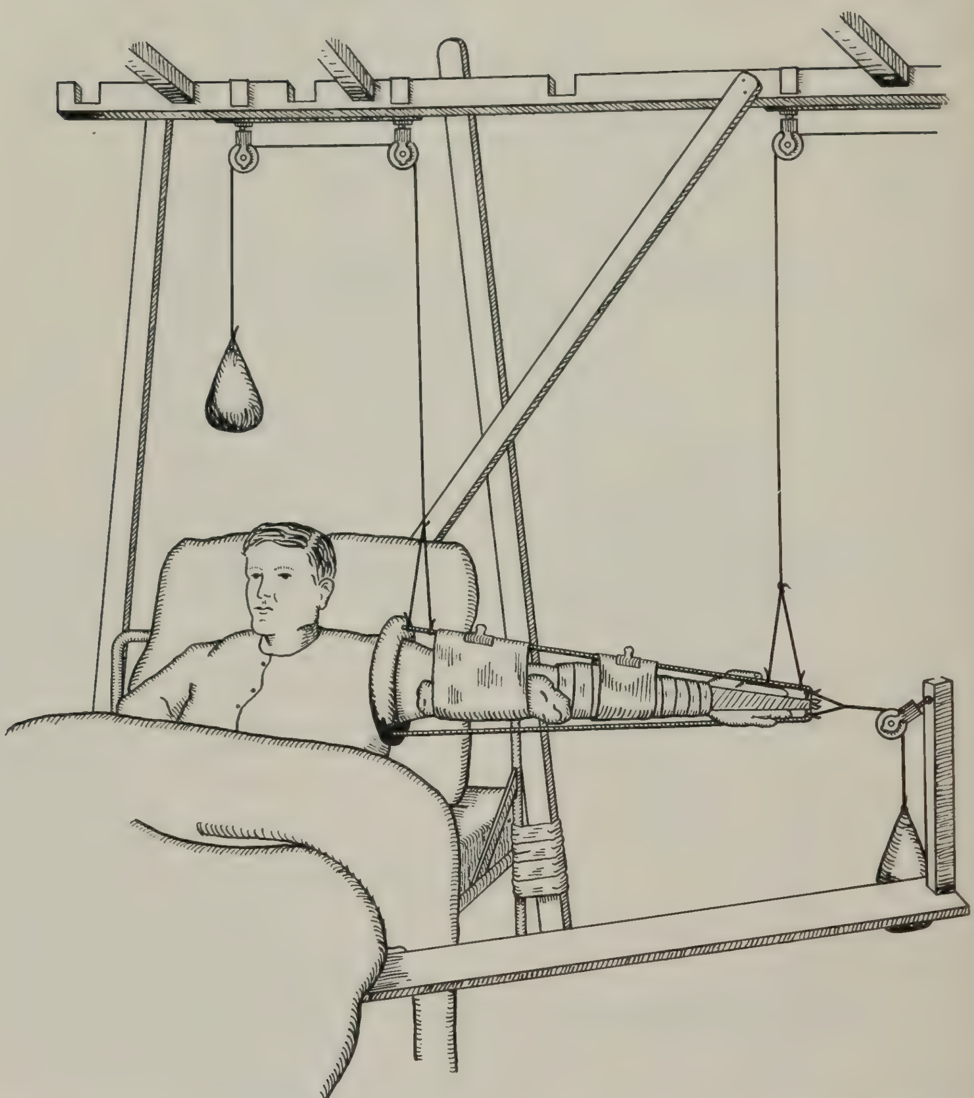

Fig. 9.—Thomas traction arm splint applied with rods in vertical place and arm slung from upper rod as is sometimes necessary because of position and magnitude of wound. Traction should be applied by attaching straps to end of splint. Light additional traction may be attached directly to the splint

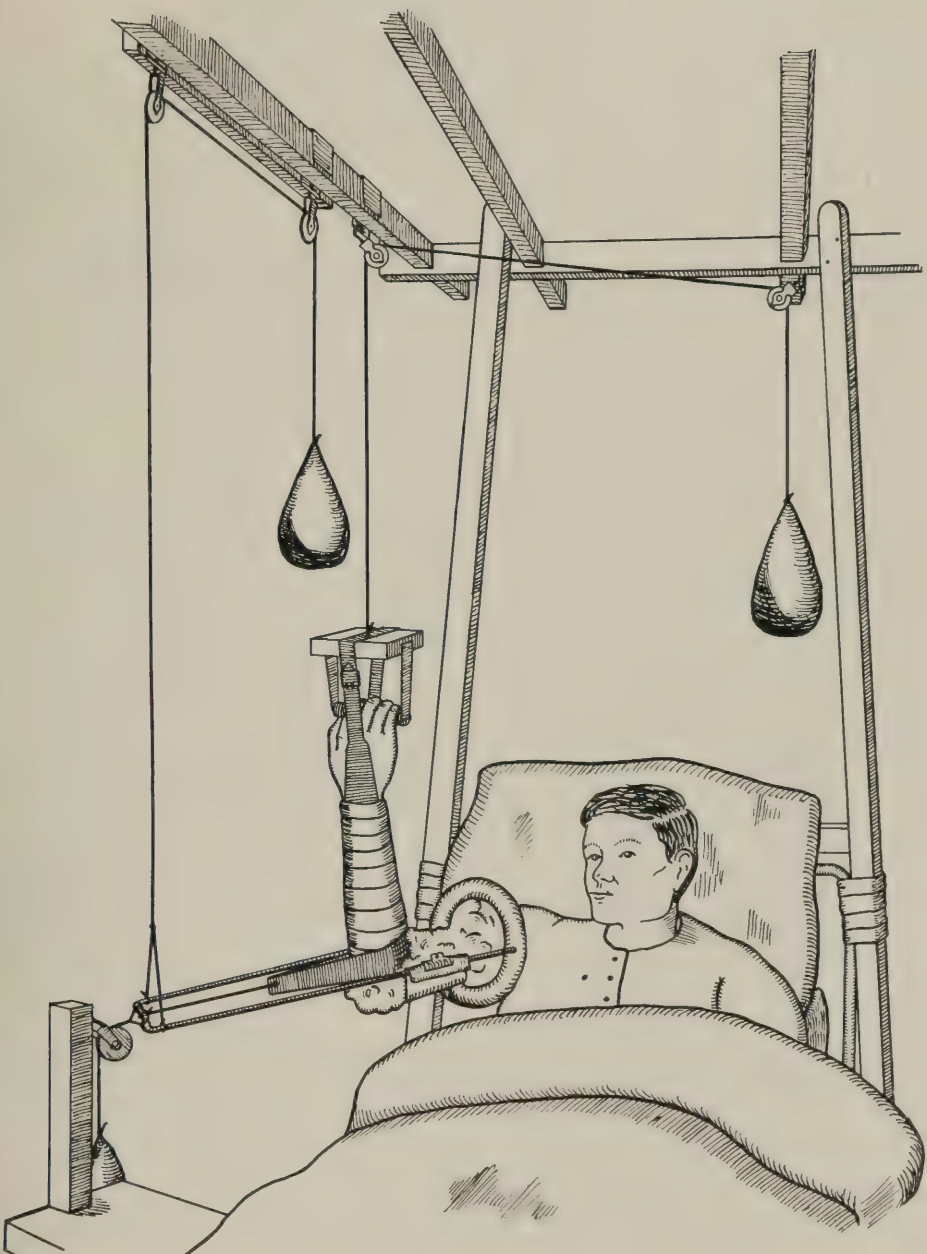

FIG. 10.—Thomas traction arm splint applied to obtain traction on the lower fragment and at the same time to allow flexion of elbow. This position is sometimes necessary with fracture of the lower third of the bone. Traction by adhesive plaster to the skin is preferred, but because of the nature of the wounds this may not be possible

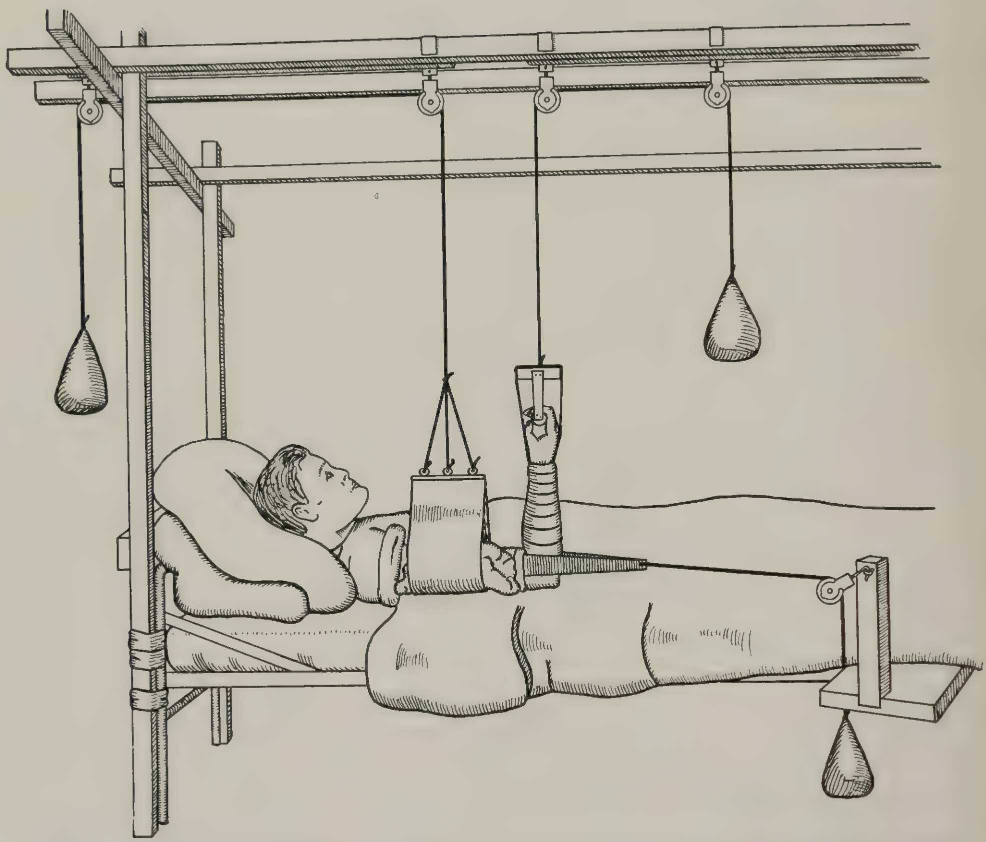

FIG. 11.—Treatment without splints, due to extensive wounds. The extension should be obtained by adhesive plaster to the skin wherever possible, but if not feasible the sling as pictured in Figure 10 may be used

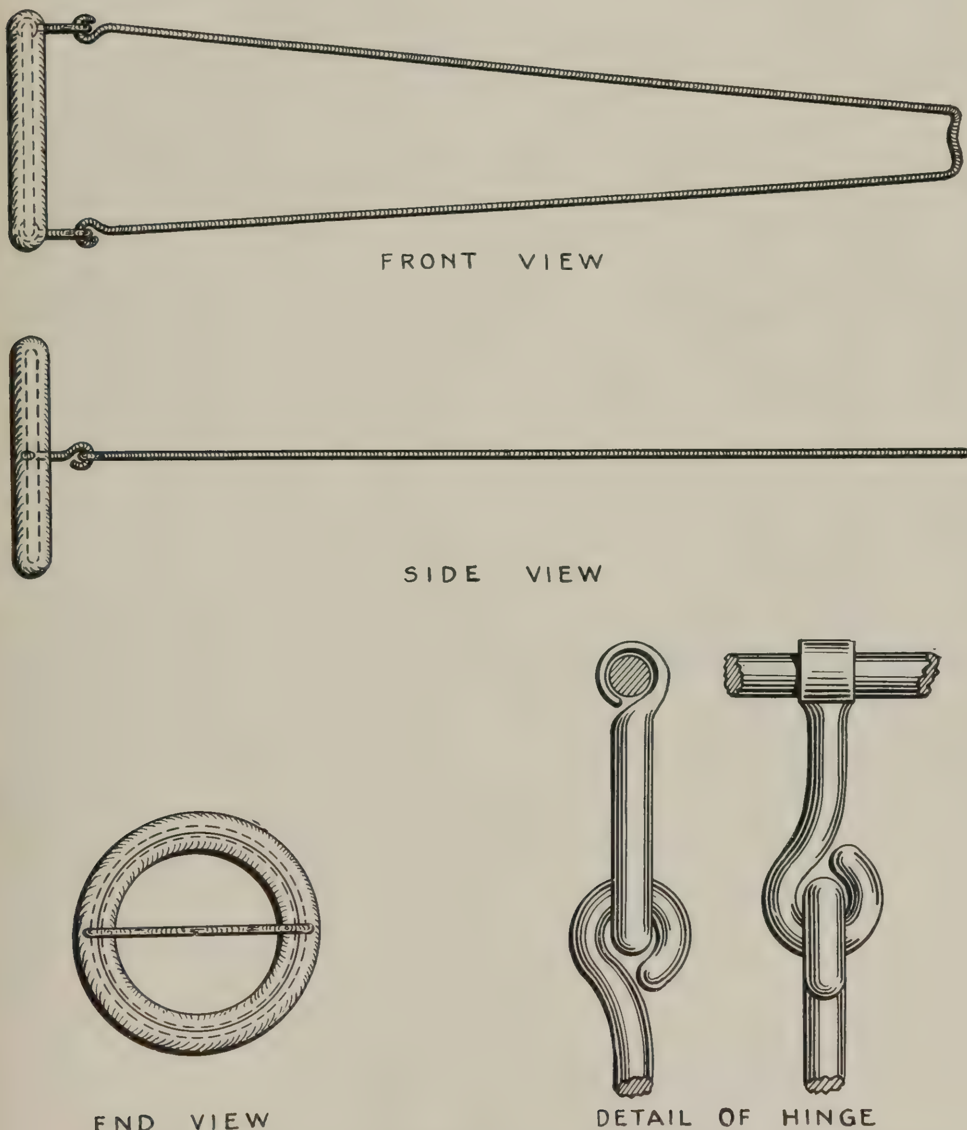

FIG. 12.—Mechanical drawing of hinged traction arm splint. Uses: Injuries to shoulder joint; to shaft of humerus; to the elbow joint; to the forearm. Should always be used as splint for transportation

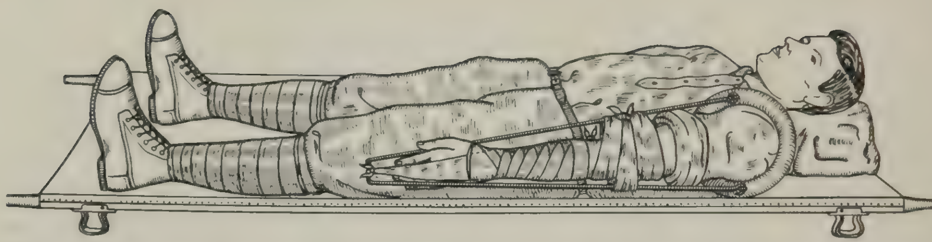

FIG. 13.—Hinged traction arm splint. For application the rods should be opposite the anterior and posterior surfaces of the arm. The hand should be two-thirds fully supinated. The slings should be applied so as to best support the fragments and to interfere the least with the wound. This type of splint may be used for all the purposes of the Thomas traction arm splint. The Thomas traction arm splint, however, should not be used for a transport splint unless the rods are bent at a point 2 inches away from the ring so that the plane of the ring will make an angle of 30° with the rods instead of 90°, the normal position

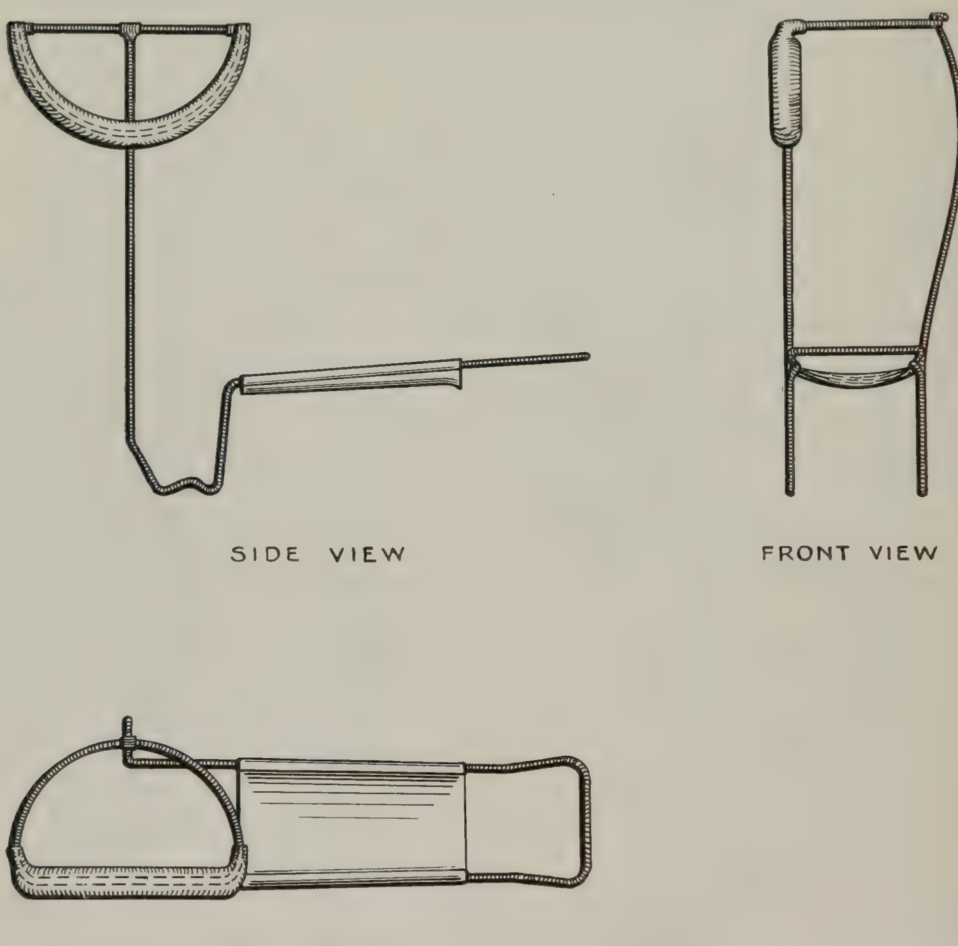

FIG. 14.—Mechanical drawing of Jones humerus traction splint. Uses: Injuries to the shaft of the humerus, in which traction on the humerus and flexion of the elbow joint are desired; to the elbow joint in which flexion is desired; to the forearm

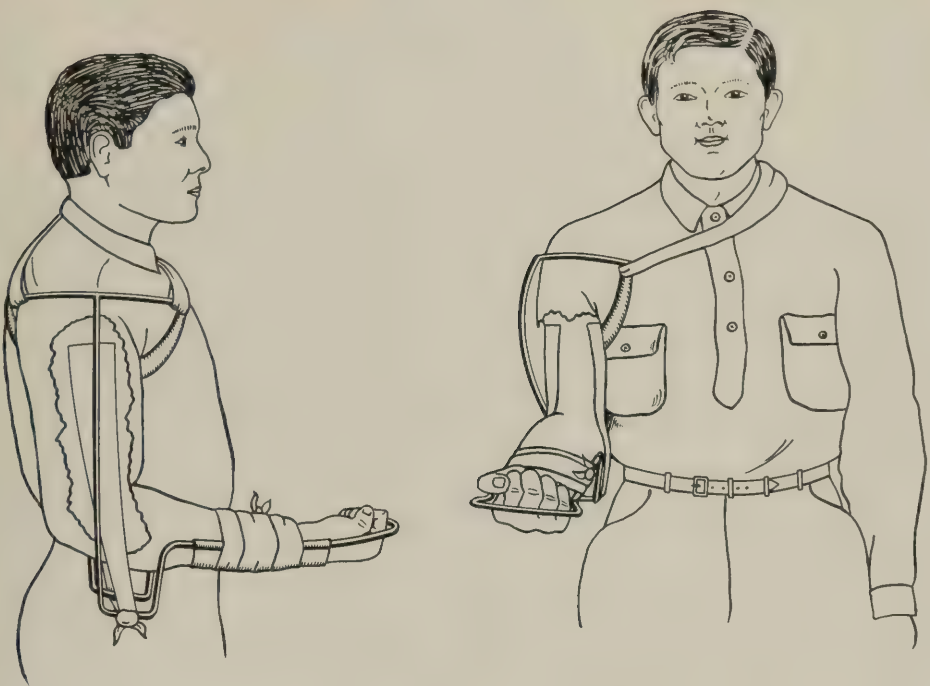

FIG. 15.—Jones humerus traction splint. This type of splint is to be used for fractures of the humerus at or below the middle of the shaft in which flexion of the elbow is desired. The splint is to be used largely for ambulatory treatment. The hand should be two-thirds fully supinated. The traction should be obtained wherever possible by adhesive plaster to the skin. The strap across the opposite shoulder to support the splint should always be used and adds much to the comfort of the patient

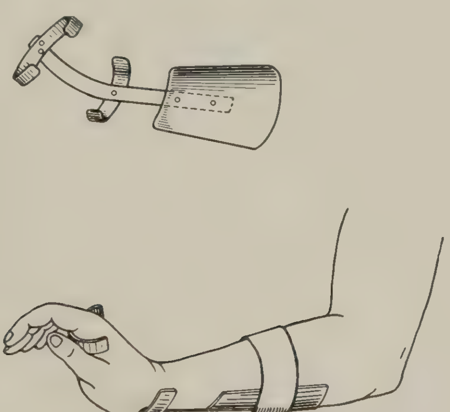

FIG. 16.—Jones "cock-up" or "crab" wrist splint and application. Uses: To retain the position of dorsal flexion of the hand in cases of injury to the wrist and in nerve and muscle injuries which produce wrist-drop; to obtain full extension of fingers add piece of ladder splint material, or use ladder splint material alone

Fig. 17.—Hinged half-ring thigh and leg splint, for transportation use in injuries to the shaft of the femur; injuries to the knee joint; injuries to the leg

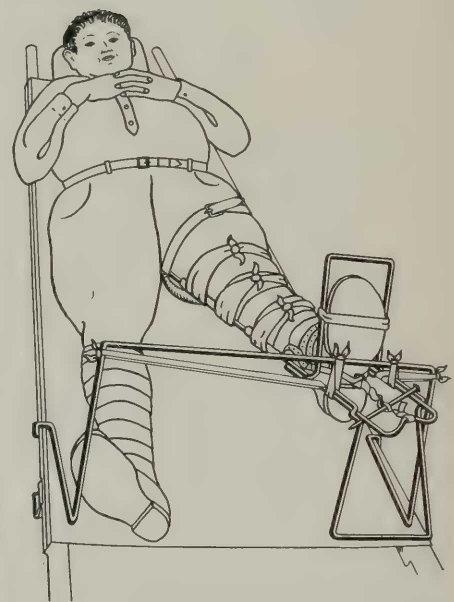

Fig. 18.—This and Figure 19 show method of applying traction to fractured lower extremity in the field. Note the stretcher bar suspending the traction splint and the wire foot support holding the foot at right angle to the leg; also note the method by which the splint is secured to the stretcher bar by the use of bandages. The shoe should never be removed in the field

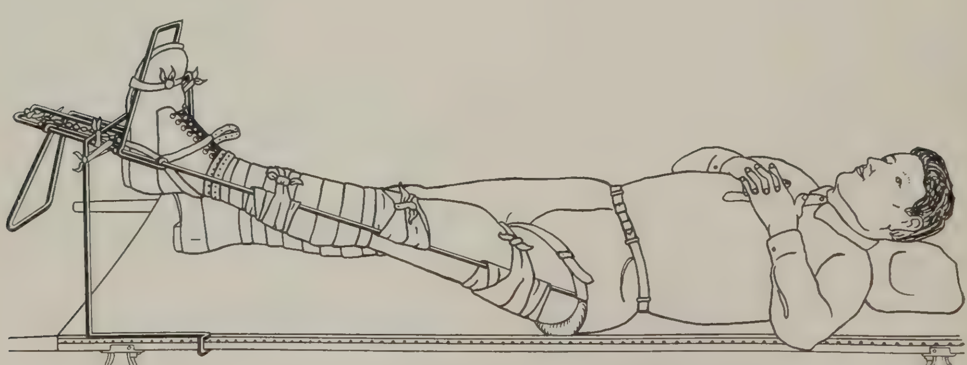

Fig. 19

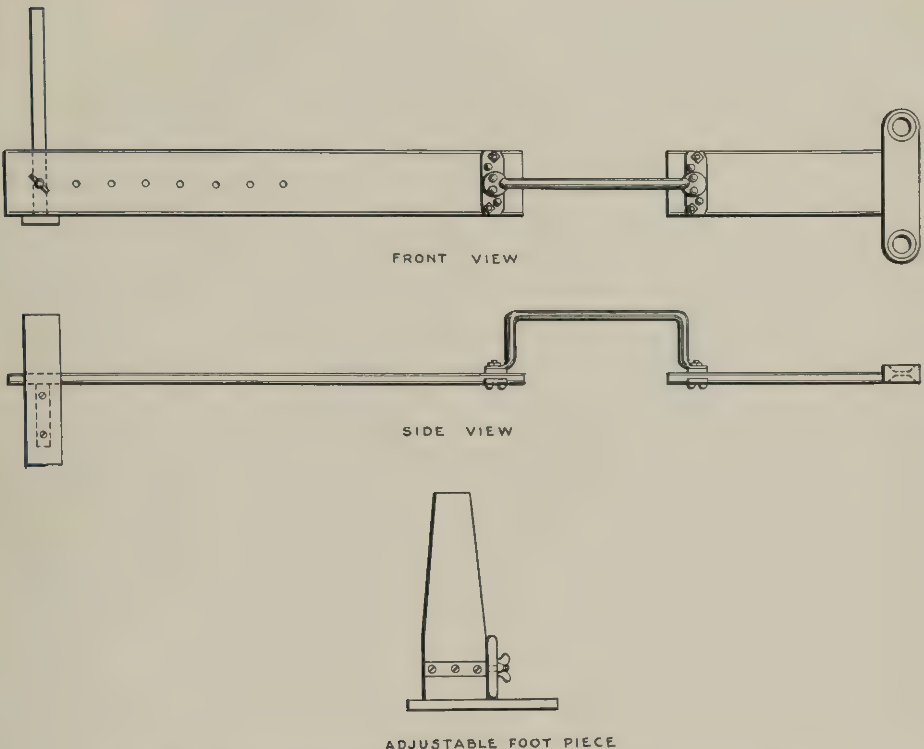

FIG. 20.—Mechanical drawing of long Liston splint with interrupting bridge of iron wire

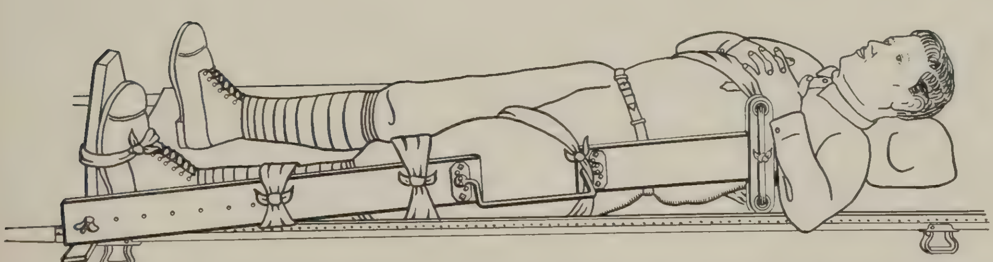

FIG. 21.—This and Figure 22 show the long Liston splint with interrupting bridge. Applied for stretcher transport only. Uses: Injuries of the pelvis requiring fixation in transport; of hip joint requiring fixation and abducted position in transport. The upper thigh and hip should be supported in transport by a sandbag or pillow or spica bandage. Note the thoracic and leg bandages and bandage passing from thoracic bar over shoulder. Additional slings for support of leg or thigh may be added as desired, and if the bones are much comminuted a piece of wire ladder splint material applied to the back of the leg and thigh under the slings furnishes more complete support

FIG. 22

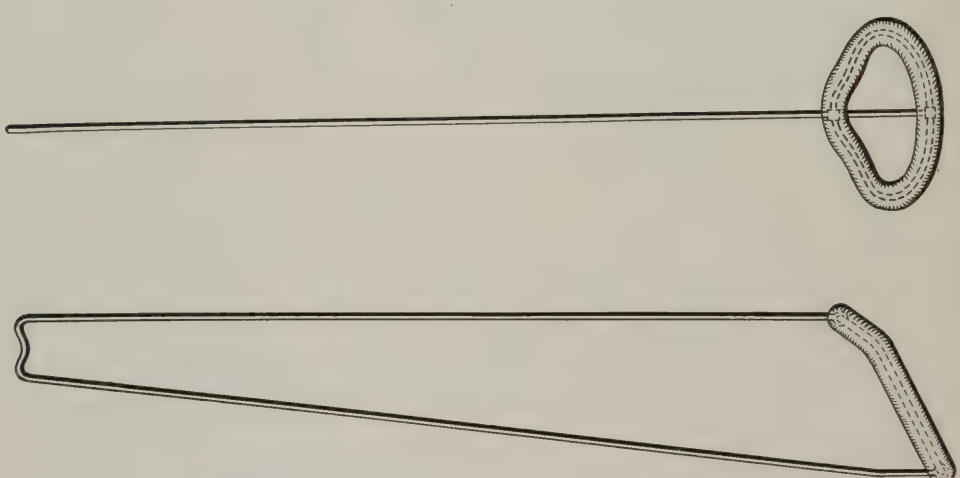

FIG. 23.—Mechanical drawing of Thomas traction leg splint. Uses: Injuries to the shaft of the femur; to the knee-joint; to the leg

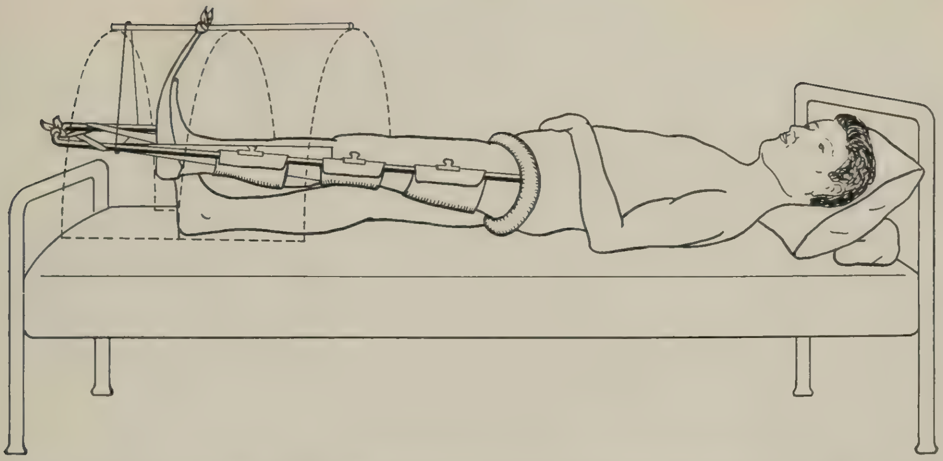

Fig. 24.—Thomas traction leg splint with traction attached to end of splint and splint slung from cradle. The position of the foot at the right angle is held by sole band, also attached to the cradle. The supporting slings upon the splint should be of sufficient number to give thorough support to the leg and by the adjustment of these the position of the fragments may be modified as is desired

Fig. 25.—Thomas traction leg splint applied with suspension to the Balkan frame. Additional traction is attached to end of splint and suspended over pulley. The chief traction should always be obtained by attaching the traction straps directly to the end of the splint and this adjusted with the Spanish windlass. Additional traction may be added by direct pull on the splint. The position here shown is that which is desired for fractures above the junction of the middle and lower thirds and below the neck. The same position here shown is desirable for fractures of the femur below this level. By adjusting the position and tightness of the slings the position of the fragments may be modified. For fractures of the middle of the thigh the sling under the middle of the thigh should be tight, since the fragments usually sag downward. For fractures at or below the junction of the lower and the middle thirds the sling under this region should be tight, because of the same usual backward sag of the fragments. The traction bands should extend as near the seat of the fracture as the condition of the wounds will permit

FIG. 26.—Showing the use of Ransohoff "ice tongs" in conjunction with the Thomas traction leg splint, to secure skeleta traction. At times, because of difficulty in replacing the fragments especially with fracture of the lower third of the femur, skeletal traction is desired until the healing is sufficiently advanced to make the more routine treatment possible. If such skeletal traction is needed the "ice tongs" are preferable to other methods, and if used the points should be inserted just above the widest part of the femoral condyles, as far forward as possible, avoiding the knee joint. This method of treatment is not compatible with transportation, and should be reserved for special cases. Subsequently if transportation becomes necessary before union has taken place the usual methods of treatment should be employed

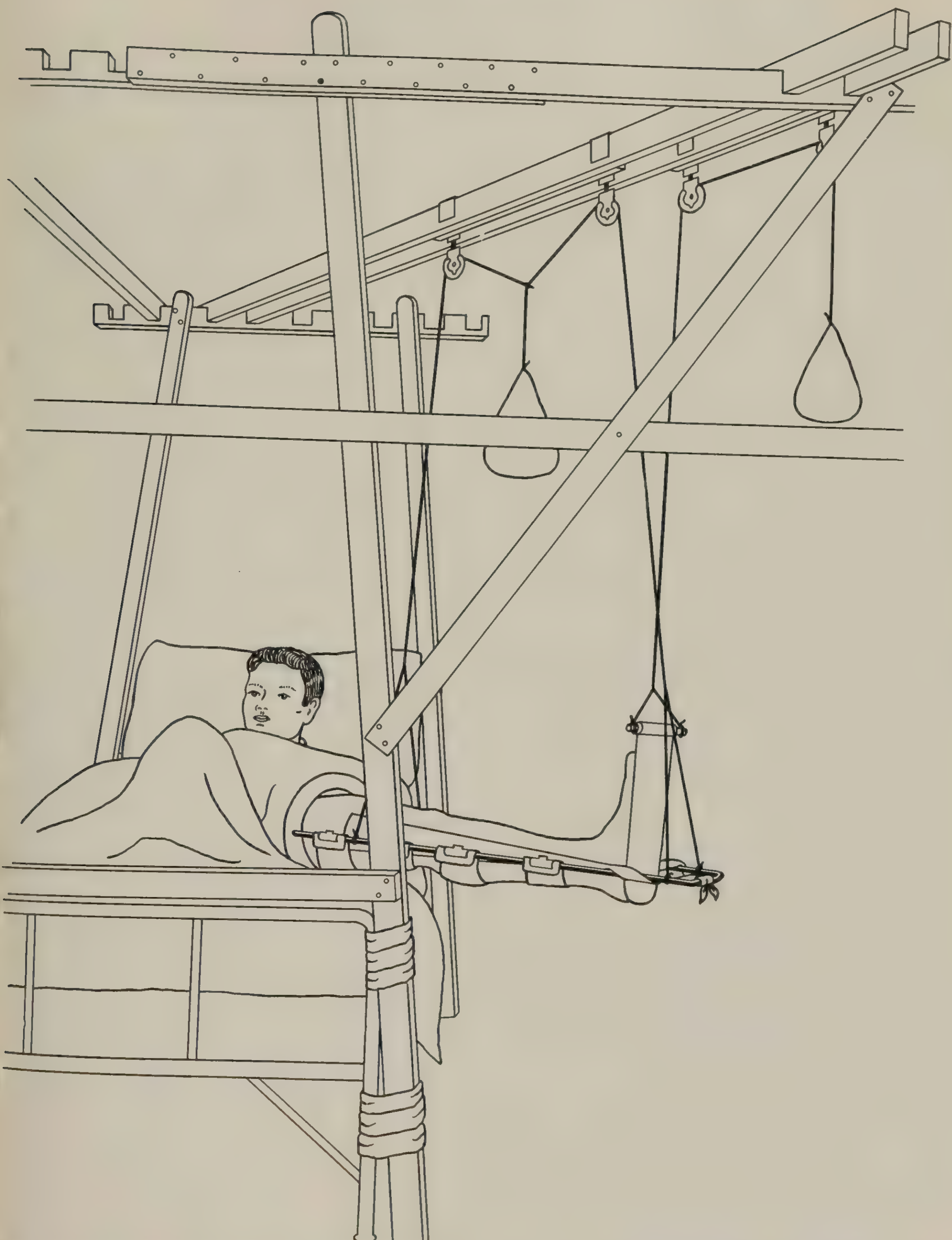

FIG. 27.—Position for fracture of neck of femur or fracture into the trochanter. Only such traction as is required to steady the leg should be used, since the crowding of the bones together in this position is desired. Because of the extensive character and location of the wounds the use of the Thomas splint is often not possible, and under such conditions the Hodgen splint straightened at the knee should be used

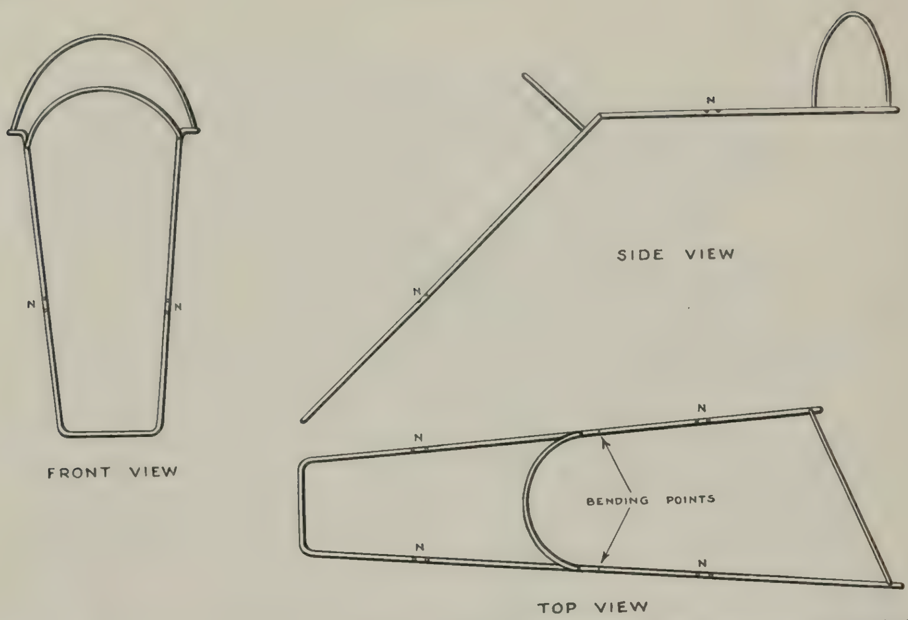

FIG. 28.—Mechanical drawing of anterior thigh and leg splint, Hodgen type. Uses: For suspension of the limb from overhead support in injuries to the thigh and leg. NOTE.—At places marked N the rods should be notched or roughened to prevent the supporting straps from slipping out of place

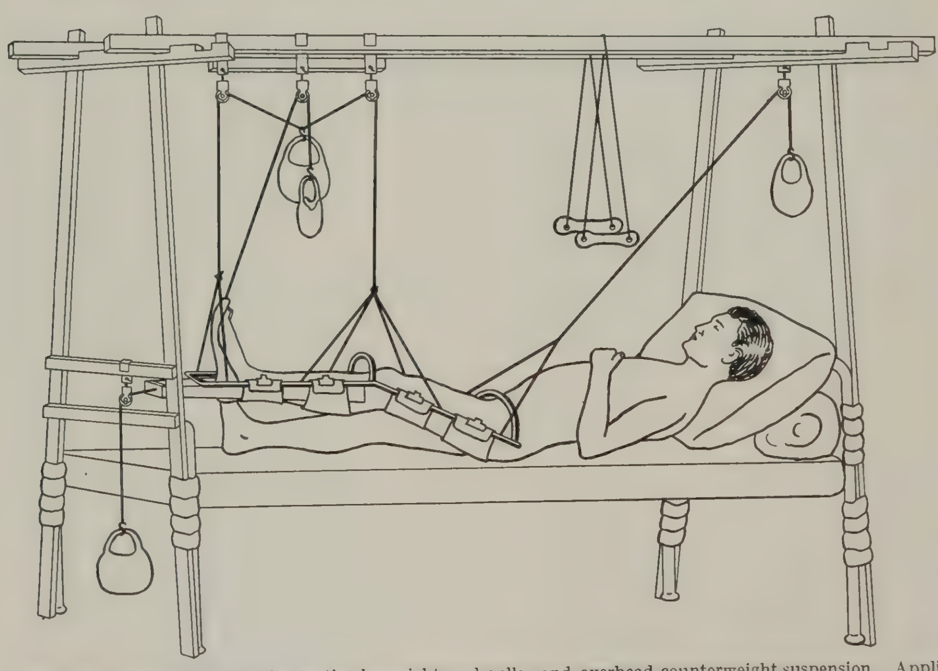

FIG. 29.—Wooden bed frame, for traction by weight, and pulley and overhead counterweight suspension. Application for lower limb injuries, limb in anterior thigh and leg splint, Hodgen type. Uses: For suspension of limb from overhead support in injuries of thigh and leg. This splint is used simply for a frame to sling the leg in case the nature of the wounds makes the Thomas splint impossible. The traction straps should be attached directly to the weight and pulley, and should not be attached to the splint. By careful adjustment of the slings the position of the bone fragments can be controlled

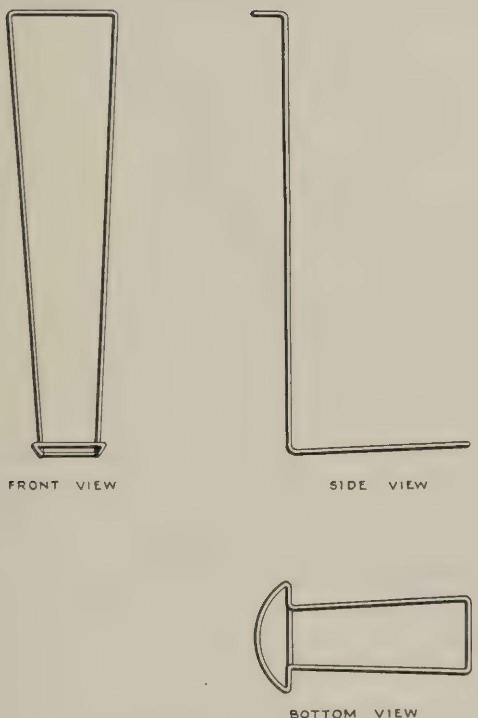

FIG. 30.—Mechanical drawing of Cabot posterior wire leg splint. To be used with or without side splints. Uses: Injuries to the soft parts of the lower limb requiring fixation in transport; slight injuries to the knee or ankle requiring fixation in transport; fractures of the fibula; wounds of the ankle joint; injuries to the foot. The rods of the splint should be thoroughly padded, and they may be bent to allow flexion at the knee if desired. Side splint of wood or wire ladder may be used in connection with the splint if desired

FIG. 31.—Cabot posterior wire splint applied with supination of the foot. When used for injuries of the ankle and tarsus the entire splint should be twisted so that the foot piece will be inclined and hold the foot in the position of varus. The object of this position is to overcome the natural tendency toward the valgus deformity with the subsequent development of flat foot

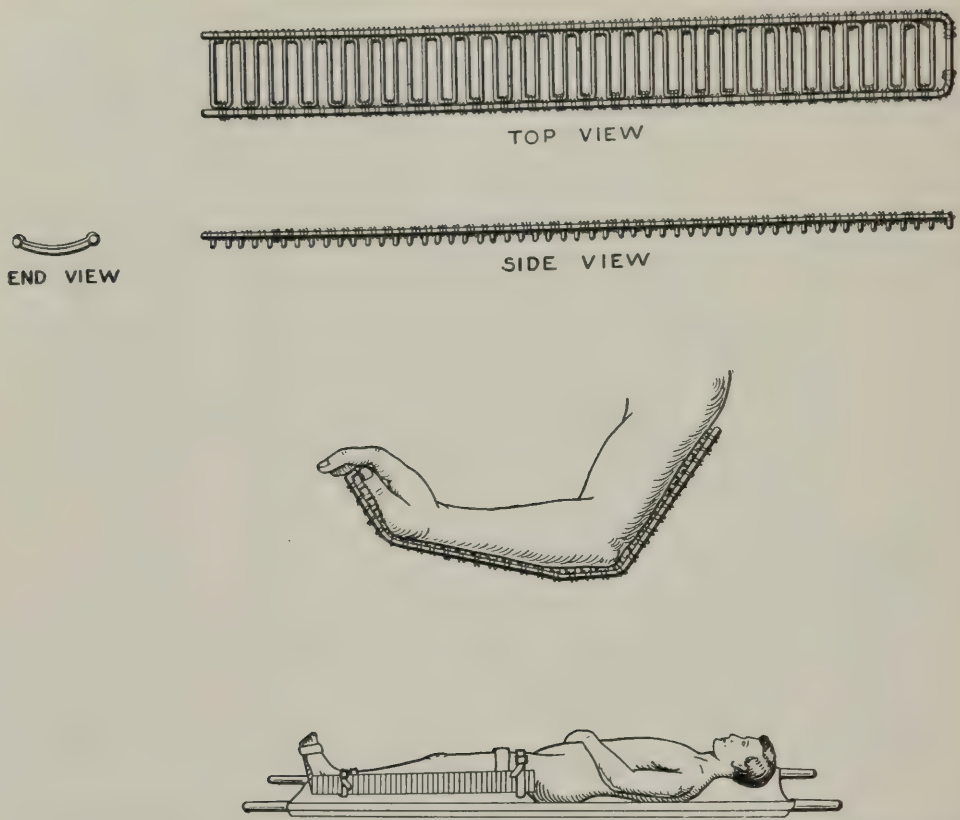

Fig. 32.—Mechanical drawing of ladder splint material. Uses: For shoulder, upper arm, elbow, forearm, wrist, hand, lower leg, ankle, and foot splints; side splints in combination with Cabot posterior wire leg splint; coaptation splints; where malleable light splint material is to be desired

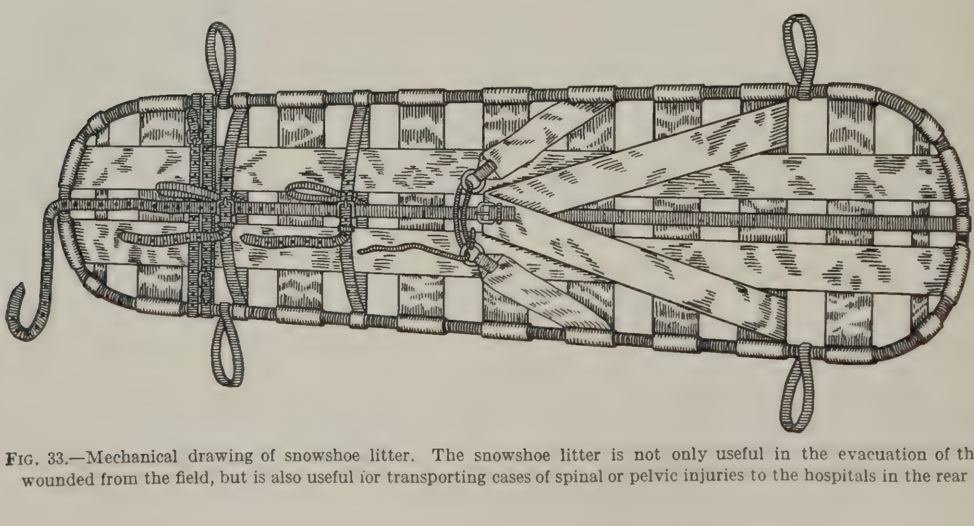

Fig. 33.—Mechanical drawing of snowshoe litter. The snowshoe litter is not only useful in the evacuation of the wounded from the field, but is also useful for transporting cases of spinal or pelvic injuries to the hospitals in the rear

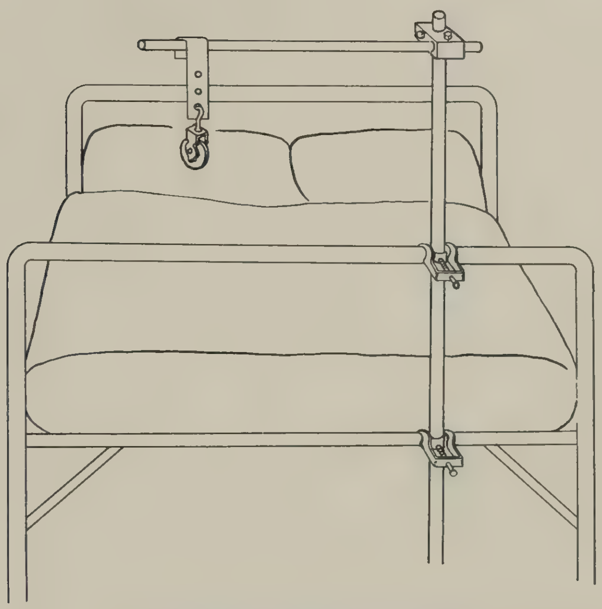

FIG. 34.—Maddox unit clamps, iron pipe and bed frame clamp. Applied for simple leg traction by weight and pulley

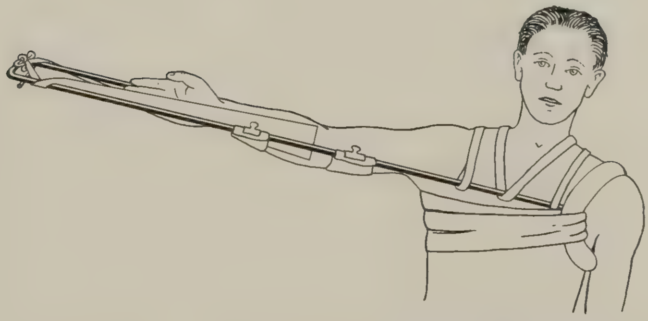

FIG. 35.—Special use of Thomas traction leg splint. Applied over uninjured shoulder, for shoulder and arm injuries. NOTE.—Shoulder straps for supporting splint; thoracic swathe for counterpressure; supporting slings clipped to rods; traction bands; nail twister for maintaining and regulating traction

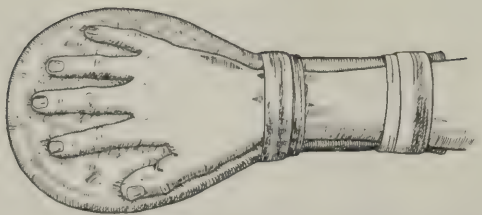

FIG. 36.—Hand and wrist splint. This splint should be used for the lacerated wounds of the hand or wrist, being applied over the usual large dressing. While the splint is intended largely for use in the early stages of such injuries, it may be continued into the later stages, provided the padding is so applied that the position of the hand and fingers with reference to ultimate function is maintained. When this later stage of the treatment has been reached, a molded plaster-of-Paris splint, or a carefully molded piece of wire ladder splint material, is usually more satisfactory

FIG. 37.—Mechanical drawing of abduction arm splint. For injuries of the shoulder or of the humerus in the upper third it is desirable to maintain the abducted position after the patient is allowed to be up and about. For this purpose a well fitting plaster-of-Paris dressing may be applied. If wounds are present or if less rigid fixation is required, the splint pictured should be used. This is adjustable as to the amount of abduction by use of the shoulder chain, and can be applied with the arm fully extended, in which position light traction is possible, or the arm may be flexed to the right angle or the half this position by the adjustment at the elbow. The arm should be held with the humerus in two-thirds outward rotation. The splint is reversible, so that it can be used upon either the right or left side

in obtaining raw material, manufacture presented many problems. A large warehouse was established [19] for the accumulation, sorting, and packing of splints as they came from the factories.

During the months of October and November, 1917, there was much to do in the way of inspection of the output of the splint factories, the board felt keenly its responsibility in establishing a definite standard to which manufacturers of splints should be held. The method followed was to look over the finished product of a factory, comparing it with the working model in the presence of the foreman. After an appreciable number had been collected, the chief surgeon, A. E. F., directed that a certain supply be kept always in that warehouse and that the remainder be shipped weekly to the two medical supply depots,[19] one at Cosne and the other at Is-sur-Tille.

The entire proposition was put on a good business basis. In this connection an effort was made to look ahead in the purchase of supplies so as not only to prevent idleness in the factories for want of material to work with, but also to speed up constantly their output, much assistance being given in this direction by the purchasing department of the American Red Cross. An accurate set of mechanical drawings of the standard splints was made. Early plans were made to have a shop where new ideas in appliances could be worked out; ultimately, this idea was of great value, as several new and valuable appliances were developed in the shops.

Early necessity also was foreseen for having a splint repair shop, where broken and soiled splints could be renovated. At the beginning, however, this seemed very remote, and no definite steps were taken to get this very necessary adjunct to the splint supply of the Army started until well along in the spring of 1918. Then it was started at Dijon, where it served not only as a repair shop, but also as a factory for new splints, and it delivered, in the days of greatest stress, a goodly number of splints each day to the nearby medical supply depot at Is-sur-Tille.[19]

To determine approximately the number of various kinds of splints that would be needed by the American Expeditionary Forces, percentages of the various fractures, from statistics of the casualties that had occurred in the British and French Armies were figured. Upon this basis the splint board, early in October, 1917, placed with the American Red Cross an order for 28,100 splints.[19] When about 50 per cent complete, the order was increased to 100,000 splints of all types, in the hope that this number would be adequate for the American Expeditionary Forces for a considerable part of the first phase of the military effort.

The varieties and numbers of splints in this first order were based on the theory that we would have about the same proportion of fractured arms and legs among our casualties as the British and French. On the whole, it was not a bad method of apportioning the numbers of the different types of splints, as subsequent orders proved. The full list of splints, splint accessories, and appliances at the disposal of the Medical Department when the 1st Division began to enter the line in the Ansauville sector north of Toul, January 14–15, 1918, was the following: Splints: Thomas traction arm; hinged traction arm; Jones humerus traction; Jones "cock up" wrist; Thomas traction leg; hinged half-

ring (Blake-Keller) thigh and leg; long Liston interrupted; anterior thigh and leg, Hogden; Cabot posterior wire leg; wire-ladder splint material. Splint accessories: Balkan frame; Maddox pipe frames; galvanized net wire gauze, in rolls; clamps, rope, pulleys, weights, etc.

It is worthy of note that this was the entire splint equipment chosen by the splint board and held by it to be adequate for the Army's need. The number of splints having thus been reduced to 10, it remained to be seen whether this number was sufficient, or perhaps would be susceptible of further reduction, in the practical test soon to be given it.

As events soon proved, however, it became necessary on several occasions to order an extra supply of a certain splint, and indeed, to place large orders for additional supplies of the whole list. Thus in the latter part of June, 1918, when for over a month there had been the severest kind of fighting north of Paris, in which three divisions of the American Expeditionary Forces had suffered heavy casualties, an absolute shortage of splints occurred. On the first of July it was found that the quantity of splints and associated supplies was running very low in the advance area. It was also found that, due to the slow delivery of raw material, the shops were not able to produce up to their full capacity. Every effort had been made to secure delivery of this raw material which consisted of various sizes of iron wire rod used in making the splints. All forms of business in Paris were feeling the strain of the suspense caused by the approach of the German Army. On this account, most of the reserve stock in the Red Cross warehouses in Paris had been distributed. Feeling the necessity for some immediate decisive action, arrangements were made with the French for the immediate release of a considerable tonnage of the raw material needed.

The "third Army order," which called for 54,000 splints, was then formulated. To complete it there was needed 45 tons of steel wire rods, and, as above stated, this was in large part obtained from the purchasing department of the Army.[19]

On October 26, 1918, the status of the splint question was as follows:[19] The Army had ordered a total of 462,350 splints; of these 229,927 had been made up to that date. The total number supplied to the American Expeditionary Forces was 177,468.

At this time the entire order was about 50 per cent complete, but since the raw material to complete the entire order was on hand in the storehouse in Paris, the remainder could have been executed by the early months of 1919.[19]

During the winter 1917–18 a weekly conference was held with the orthopedic surgeons from the different divisions in order that the details might be worked out and made standard. In order that the system would work uniformly and successfully, it was necessary to settle points like the following: The number of splints which should make up the equipment of a division in the field; how these splints should be divided among the various units of the division; what should be the standard equipment of a battalion aid post; what should be the standard splint and dressing equipment of a field hospital, a mobile hospital, an evacuation hospital, and a base hospital. These and numerous other questions had to be agreed upon, with the realization that the

men had had but little experience and that changing conditions would change a good many of the rules laid down.

Certain minor pieces of apparatus had to be supplied to make splint application efficient, notably a stretcher bar. It was found while demonstrating the splints to the medical officers of the 26th Division that it was necessary to elevate the end of the Thomas thigh splint to a considerable angle when the stretcher was placed in the small Ford ambulance in order to close the tail gate of the car. An appliance to suspend the splint had to be devised immediately as it was expected then that the troops would be in the line in about two weeks time. A competent stretcher bar was worked out and adopted by the splint board, and 500 of them were ordered made. They were supplied in time to be distributed to the ambulance companies of the 1st Division before that division entered the trenches.

On the night of January 15–16, 1918, the 1st Division moved into the trench positions in the Ansauville sector.[20] This portion of the line had long been quiet, being dominated by Mont Sec, a high hill which the Germans at that time held. In consequence, the trenches were in a poor state and the entire problem of the evacuation of the wounded was one of great difficulty, as it involved long carries by stretcher. It was here that the first actual experience came. Soon there was a daily and nightly run of casualties arising from the increase of artillery activity and from raids. These wounded men had to be carried usually over a mile through a winding trench before they reached the battalion aid post. At night, it was frequently possible to carry the wounded out over the top of the trench, thus immensely lessening the burden of the long carry; in the daytime this was not practical, as a rule, because the country was very flat.

In the town of Mandres an aid station was functioning as a "sorting station," the first post of this kind established in the American Expeditionary Forces. The surgeon in charge was much interested in the problems of the orthopedic department, and he devised a "trench litter" on which, like the Stokes litter used by the Navy, a wounded man could be carried on his side, face down, or head up or down, without slipping off. This was found to be valuable, was approved by the Surgeon General and by the splint board, and was adopted as part of the standard equipment. It proved especially valuable to Artillery troops who as a rule had their aid posts in deep dugouts with narrow entries.

During the last two weeks of August and up to September 12, 1918, efforts were directed toward getting a sufficient supply of splints and accessories forward to equip the First Army, in preparation for the St. Mihiel operation. Supply depots were organized at the Justice group of hospitals and at Souilly—the first to take care of the main effort which was to proceed from the old trench positions north of Toul; the second was to take care of the troops and hospitals on the left flank of the St. Mihiel salient. A system was planned for the return to the front of all splints that had been taken out, by having an order issued that made it imperative for ambulance drivers to exchange with hospitals where they had unloaded wounded, one for one, in blankets, splints, and

apparatus, so that there would be a return flow of these appliances to the divisions.

Orders similar to the following were issued in army, corps, and divisions, which defined the use that was to be made of the splints:

HEADQUARTERS FIRST ARMY, AMERICAN EXPEDITIONARY FORCES,
OFFICE OF CHIEF SURGEON.

Memorandum:

For the purpose of securing uniformity of splinting and the best results in fracture cases, the following instructions are issued:

1. All fractures are to splinted at the earliest possible moment; this means, where the man falls. If this is impossible, the splint should be applied at the battalion aid post. No fracture should pass through the advanced dressing station, "triage," unsplinted.

2. The Thomas full or half ring traction splint will be used for all fractures of the lower extremities from the pelvis to just above the ankle.

3. The Cabot posterior wire splint or wire ladder splint is to be used for all wounds of the calf, ankle, and foot.

4. All wounds of knee, no matter how slight, are to be splinted.

5. The hinged traction arm splint will be used in fractures of the humerus, elbow, and upper forearm.

6. Ladder and wood splints will be used in fractures of the long bones only where traction splints can not be efficiently applied and to supplement such splints.

7. The fact that traction is the immobilizing factor in all traction splints should never be lost sight of and the utmost care should be taken to apply the proper degree of traction to obtain fixation.

* * * * * * *

MANUAL OF SPLINTS AND APPLIANCES, SECOND EDITION

In October, 1918, a second board of medical officers was organized to go over the work of the first splint board.[21] In this way, it was desired to continue this work, adding to it where necessary, and also eliminating anything that might be found to be superfluous.

The new board went over the samples of splints and appliances then in use. The board used the first edition of the splint manual as a model to write another booklet, similar in every respect but containing the changes that the board had seen fit to adopt.[18] In a few days the manuscript was ready; it was given to the American Red Cross to have 35,000 copies printed. By the first of February, 1919, its distribution began. In this second edition of the manual it was possible to set down the exact figures for the requirements of field medical units, and various types of hospitals, as to splints and splint accessories.

ORTHOPEDIC DEPARTMENT, A. E. F.

Early in November, 1917, when relatively few American troops were in France, a meeting of the senior orthopedic surgeons of the American Expeditionary Forces was held to go over the situation and plan the course of action which the orthopedic service, A. E. F., should follow. It was decided that it was not the time for the institution of elaborate plans of organization, but one in which the best service could be given by undertaking in a small way the evident problems that faced the American troops and hospitals, and by using the nucleus of well trained medical officers who had been sent to England to serve as orthopedic surgeons with the British, a few at a time, in places where they

could accomplish something. In that way, an organization could be built up that would fit accurately into the military machine that was developing at the same time. Headquarters, professional services, were established at Neufchateau, the center of the divisional training area.[22]

By the first of January, the organization of the orthopedic department had been worked out and another group of officers was ordered to the American Expeditionary Forces from England.[23] It was realized that the fracture case needed what the French had termed a system of "radial control"; that is to say, a wounded man passing from front to rear must always be under the care of surgeons who understand what has happened before they treat the man and what is going to happen after he is sent on. This system should be under the direction of one man, this man to be responsible. It was decided that the department of orthopedic surgery should be held responsible for the "radial control" of fractures, and bone and joint injuries.[24] Under this system, one orthopedic surgeon was made responsible for the splinting in the area of the divisions, corps, and army; another was responsible for the splinting and treatment given to the wounded in the mobile and evacuation hospitals. A third man was to have the responsibility for the fracture treatment in the base hospitals in the intermediate and base areas. Over this system, the chief of the department was to exercise supervision, maintaining the necessary personnel, inspecting the entire "radius" from front to rear to discover and prevent any deterioration in the character of treatment at any of the stages. In short, here was the organization necessary to see that the standard of splinting was first taught and afterwards carried out.

In the reorganization of the professional services, American Expeditionary Forces, in June, 1918, the director of orthopedic surgery, A. E. F., became known as senior consultant, orthopedic surgery; his assistants, with supervisory duties over hospital centers and other formations were designated consultants.[25]

After some weeks of experience with actual combat conditions, the director of general surgery, A. E. F., arranged for division orthopedic surgeons to take over the responsibility of all the surgery that arose from the time a soldier was hit until he reached a hospital. The following circular concerns not only this subject, but also outlines the general assignment of responsibility to the orthopedic service, in so far as the share of that service in case of the wounded was concerned:

Office of the Chief Surgeon,
American Expeditionary Forces,
France, 16 August, 1918.

Circular No. 46:

1. Upon the recommendation of the chief consultant in surgery, and with the approval of the director of professional services, the following instructions are published for the information and guidance of all concerned.

INSTRUCTIONS CONCERNING THE TREATMENT IN ORTHOPEDIC CONDITIONS INCLUDING FRACTURES AND JOINT INJURIES

2. The work of the division of orthopedic surgery in the medical organization of the army divides itself quite clearly into two parts, one having to do with the preparation of the men for the expected combat, and the other assisting in their recovery if wounded. The first has to do with saving men for service who would otherwise be discharged as physically

unfit and also as the result of careful training, increasing the number of days that should be expected of the men for active duty. The second has to do with the saving for service of men who but for such work might not have lived, or been so crippled as to be of no use to the army.

3. Without such methods of treatment available for those needing such care in the precombat or training period, large numbers of men will be lost for active duty as the ordinary medical measures can only give temporary relief.

4. Without such methods in cases of combat or other injury there will be much unnecessary loss of function and much of the acute surgical treatment will be purposeless.

5. In each of the large hospital centers, a base hospital with special personnel and equipment for caring for such cases will be installed, while in the detached base hospital special services will be established so that there will be the least possible transferring of cases from one hospital to another.

6. Consultants in orthopedic surgery will be assigned to groups of hospitals whose function it will be to keep in touch with the othopedic work of the given group. These consultants should be freely used by the staff of the respective hospital and can be reached through the commanding officers of the hospital centers.

7. To best accomplish the purpose of the division and to make the services of its members available, the following instructions will govern.

AMPUTATIONS

8. Cases of amputation of either extremity will be assigned as soon as possible to the orthopedic service for the needed special treatment. A guillotine amputation for instance without other injuries, can usually be moved without risk in one week and with suitable measures rapid closure of the wound is usually possible so that an artificial leg can be fitted and the man get about without crutches many times in from four to five weeks from the time of the injury. It is desirable that transfer to the orthopedic service take place as early as possible before contractures have taken place so that the temporary artificial limb, in case that is desirable, can be most favorably fitted on and the most muscles used to the best advantage.

TENDON INJURIES OR INFLAMMATION

9. The cases of injury to the tendons or inflammation in or about the tendons should be assigned, as soon as the primary wound healing is well established or as soon as the acute inflammatory reaction has subsided, to the orthopedic service. Early transfer to the special services is important in order that the treatment having to do with full restoration of function in the part that has been injured or inflamed may be established at the earliest possible moment and before adhesions have formed or have become organized.

10. Cases of flat, weak, or pronated feet associated with pain, swelling, or inflammation when admitted to a hospital should be transferred to the nearest convalesent camp. From here, in keeping with the degree of difficulty, the cases should be transferred for full duty or to the orthopedic training camp depot division for training to fully overcome the weakness, or for noncombat duty under "C" classification.

11. No cases of uncomplicated flat-foot should be exempt from service or recommended for transfer to the United States as all can be made useful for military service.

SPINAL STRAINS AND WEAK BACKS, CHRONIC BACKACHES

12. Cases of weak, painful or lame backs, or of sprain of the spinal or sacro-iliac joints, should be transferred either for full duty, or for noncombat duty under class "C" classification.

GENERAL BAD POSTURE

13. Cases of general bad posture, which is commonly associated with lack of vitality or general endurance as well as being part of the condition leading to weak feet and weak backs, should be sent for training to the orthopedic training camp, depot division.

FRACTURES

14. For all cases of fracture of bones other than the head and face, or of extensive muscle injuries, it is of the utmost importance that proper splints be applied at the earliest

possible moment so that the transfer of the patient to the hospital in which treatment is to be given is associated with the least possible damage to the tissues adjacent to the injured bone. The Thomas leg splint, the hinged half-ring splint, the Thomas hinged arm splint (Murray modification), the Cabot posterior splint and the ladder splinting are appliances most needed for such work.

15. In case the fracture is compound, the wound treatment at the evacuation or other hospitals should follow the principles outlined by the chief consultant of surgical services.

16. After the primary wound treatment has been given these cases should be transferred to the orthopedic service in which the most approved methods for the early restoration of function to the injured part will be available. An effort should be made to transfer the cases to such services, wherever possible, within a week or 10 days of the time of injury, this being the most favorable time as regards bone repair. All fracture cases which, for any reason, can not or should not be transferred to one of the services as indicated above should be reported to the senior consultant in orthopedic surgery, or the orthopedic consultant of the area.

17. Simple fractures should not be converted into open fractures except under very exceptional conditions or after consultation with one of the orthopedic consultants. A result which may not be as perfect anatomically as might have been produced by open operation, may nevertheless be functionally good. This is so commonly the case that the risk of infection which is greater under the war conditions than in civil life should be avoided whenever possible.

JOINT INJURIES

18. All injuries of the joints should be protected with the same care for transport to the hospital in which the treatment is to be given that has been indicated for fractures. Suitable splints should be applied immediately and the standardized list of splints of the army provides types that will meet all the needs.

19. In case the injury is associated with open wounds, the principles of the wound treatment are those which have been laid down by the chief consultant of general surgery.

20. Since in all such injuries ultimate function is the chief requisite treatment having for its purpose the restoration of function should be instituted as soon as possible, and for this purpose, it is desirable that cases of such injury be transferred, as soon as the primary wound treatment has been given to the orthopedic service. It is important that such transfer be made before unnecessary adhesions have formed so that the restoration of function can be obtained in the least possible time. In all such functional restoration it should be clearly understood that while motion is to be encouraged at the earliest possible moment, it should consist entirely of active motions performed by the patient in which case the reflex muscular contraction will protect the joint from undue injury. All passive motion should be avoided.

21. Operations upon the joints that are not emergency in character should not be performed until after consultation with one of the consultants in orthopedic surgery.

TRANSFER TO THE UNITED STATES

22. It will be the policy to send to the United States as soon as transportable, all cases that are of class "D" type, or cases in which prolonged treatment will be required for restoration to duty.

This fixed the responsibility and also saved the situation from the confusion that would have arisen from having two sets of men doing practically the same thing, and perhaps not conforming to any standard system of instruction. Thus it came about that each division surgeon depended upon his division orthopedic surgeon to carry out a definite course of instruction for the medical department of the division.

The problem became that associated with evacuation of wounded and surgically shocked men, in addition to the treatment in the advanced area of fractures and joint injuries. During trench warfare, the evacuation problem was not so difficult; ambulance routes could be marked out on the map, and

posts could be located in definite places, and be well protected; most important of all, the hospitals where surgery could properly be done could be located within easy hauling distance of the zone of combat. Careful plans for the evacuation of sick and wounded and for furnishing a constant flow of supplies from rear to front lines by a system of exchange were worked out. It was found that the work done in the instruction of the medical department was bearing fruit, and that it was a rare occurrence for a man with a fracture to reach an aid post without a splint, usually applied very creditably.

In June, 1918, when several of our divisions were actively engaged with the enemy, our plan of evacuation had to be changed entirely because of the relatively large numbers of wounded. Hospitals had to be hastily set up at the front and there were not enough of them to meet the demand for beds; the wounded had to be carried long distances in any available vehicle of transportation. It was at this time that the supply of splints began to run low in the front area, and the system of shops and distribution was so severely taxed.

Just prior to the Meuse-Argonne operation one of the orthopedic surgeons conceived an idea that was to work out in a most fortunate manner. It was realized that a loss of time occurred in the army hospitals where much operating was going on due to the care and precision necessary to the proper application of splints to fractures after operation. This was often due to the fact that the operating surgeon usually entrusted splint application to one of his assistants. At all events, it was a well-known fact that fracture cases usually reached the hospitals much better splinted than when they left the hospitals for the journey farther to the rear. It was suggested that in each mobile and evacuation hospital, there should be one or more "splint teams," each to be composed of one officer and two enlisted men. To this end a number of junior officers and enlisted men were collected at the hospital center, Bazoilles, and were given practical instruction in the application of splints and the treatment of fractures [26] (these officers were of the orthopedic department and had had considerable training beforehand). Thereafter splint teams were assigned to each hospital in the army area where their function was to take hold of the fractures as they were admitted to hospital and to follow them through. It was a most useful addition to the chain of good fracture treatment which had had a weak link at this point; it made it possible for the surgical teams to turn out from 30 to 40 per cent more work; it also encouraged the division orthopedic surgeons in the knowledge that the work they were doing would be carried on, and not terminate at the first stopping point.

INSTRUCTION OF DIVISIONAL MEDICAL PERSONNEL

It was recognized early that something must soon be done to acquaint the officers and men of the Medical Department serving in these divisions with the standard splints and how to apply them; accordingly, at the request of the director of the division of orthopedic surgery, several medical officers who had had six months' orthopedic experience in England were assigned to the American Expeditionary Forces to help in the establishment of the work.[23] These medical officers were all men of experience as specialists in civil life, and had become familiar with the use of the traction splints. They were distributed

among the combat divisions then in training and to each of them the American Red Cross assigned a small automobile, thus making it possible for them to cover the territory occupied by their respective division. They arranged schedules for instruction of the various units of the division in the application of the standard splints.

About March 1, 1918, in the four original combat divisions of the American Expeditionary Forces, the instruction as to splinting and the supervision of the distribution of splints and supplies had reached a satisfactory stage. The medical officers who served in the four first divisions to engage in combat gained an experience as division orthopedic surgeons that made them experts on much of the knowledge that is necessary to a divisional medical officer; this practical knowledge was gained none too soon for the pressure that was to be put on all departments by the arrival of the bulk of the American Expeditionary Forces. After a few weeks of actual experience in the evacuation of the wounded, it became very evident that the instruction of the enlisted men of the Medical Department was of the greatest importance. In consequence, a large part of the effort of the division orthopedic surgeon was spent in giving lectures and demonstrations to the personnel of the various divisions; stretcher bearer units were created and these men had to be instructed in the application of splints and first aid.

These stretcher bearers felt a keen pride in learning to apply a splint quickly and perfectly and this too, when blindfolded or wearing a gas mask. The men of the Medical Department who went with the companies into action and who worked under the direction of the battalion surgeons became, as a rule, very proficient in all details of splinting.

In addition to the instruction given within the divisions, there was given at the sanitary school at Langres to each class of medical officers a set of lectures that put before them the salient points of the system then in vogue for caring for the wounded in the area of combat.

SPECIAL TRAINING BATTALION

In December, 1917, a camp was established for training men phyiscally unfit for marching and combat duty, men in whom physical defects had developed or had been accentuated since entering the Army.[27] Many of them were able to conduct their work in civil life without much or any annoyance, but they could not perform as soldiers. In some instances, the cause of the man's breakdown was not definite; in others, it was a combination of different elements such as mechanical strain, accident, change of living conditions, fatigue, and mental depression. Each man was a problem. Shirkers were among those sent to the camp, but a large number of them represented men of insufficient muscular development.

Headquarters of the special training battalion was established at Harchechamp, a town about seven miles northeast of Neufchateau.[27] There the men could be treated in large numbers, grouped as far as possible, and their ailments treated in such groups. Having determined the physical defects or habits of each individual entering the camp, treatment was established to correct the defect or defects and to develop a proper habit of carriage and life.

Work for Restoration of Proper Function

The work at the camp was planned (1) to remove the cause or causes of the defects, if the causes still existed; (2) to correct the deformity which had been produced by the cause or causes; (3) to teach the men proper use of the joints and muscles of the body; (4) to increase the muscular strength of the men so that they could not only get themselves around the camp and through the day's work, but would be able also to carry the additional weight of the soldier's equipment. The treatment was planned in the above sequence. All the training at the camp had to be carefully planned and thoroughly carried out. Accuracy and precision had to be practiced by both the officers and the men.

The men, as they arrived at the camp, were very imperfect specimens, but it was found that approximately 80 per cent could be made into useful material and returned to their organizations as fit combat men.

A card the size and shape of the Army service record was filled out in duplicate; it contained the name and number, rank, organization, age, and the date and source of admission to the battalion, and the date of entrance into the Army. Silhouettes were taken of the body trunk in profile. This was a very quick and simple method of recording posture. The personal history was recorded in brief, and, in the physical examination, especial note was made of the teeth, ears, back, feet, defects in posture, and method of using the feet. Treatment was prescribed.

The feet were measured carefully, and then the shoes fitted over two pairs of heavy socks, always giving ample room over the foot and the toe. These shoes had the heels raised on the front inside corner to throw the weight on the outside of the foot. All the men were shod in this way unless there was definite reason for not doing so. No graphic records of the feet were made.

While in receiving Company "A" the men were graded as to their aptitude and capabilities. They were given light police duty, easy calisthenics and games, with talks on the general principles of the training, and demonstrations on the care of their shoes and other equipment. Each man was issued two pairs of field shoes of proper size, adjusted as prescribed to correct his balance and whatever other defects existed. Straps and simple cleats only were employed. When this had been done and their other equipment completed, if their physical condition had sufficiently improved, they were entered on the roll of Company "A", and began their active training.

General Principles of the Training

For the feet.—The men were taught that the foot and leg are muscular members of the body, to be used in locomotion. The triple exercise was taught to strengthen the leg and foot muscles after correction by the stretching of any existing deformity. In all marching and walking, the men were instructed to toe straight ahead and bend the knee out, carrying the weight over the small toes, the weight to be kept on the outer side of the foot at all times in marching and standing, either at attention or at ease.

For the back.—The system comprised stretching of shoulders over a roll. The exercise of straight leg raising and trunk raising to strengthen the anterior

abdominal walls; the men stood with a nearly flat back, hips very slightly back, abdomen held up, chin in. The position of attention is an easy, alert posture, with knees straight, not in hyperextension, the weight equally distributed on the front and heel of the foot. The posture is somewhat like that taken by a man when he prepares to jump. He is ready for the command.

The whole camp had a general program, and each company had a special program of its day's routine, the work in each succeeding company being made progressively harder and more continuous, with shorter periods of rest.

A complete military organization was found to be necessary in order to establish and maintain discipline, without which nothing could have been accomplished in the training of these men.

Once each week the chief orthopedic surgeon selected the men who seemed fit for promotion. These men were inspected in standing and marching, and their records for persistent work during the week considered. Silhouettes were again taken to record improvement in posture. A list of men thus selected for promotion was turned in to the company commander, and those considered eligible were transferred to their original organization.

Medical Organization

The duties of each orthopedic surgeon comprised the following: At company sick call, 7.30 a. m., all light ailments were treated; all men with a temperature or any severe symptoms were immediately sent, accompanied by a sergeant, to the camp surgeon. By this method, the number of men attending the morning sick call was reduced immediately; prompt treatment and return to duty were facilitated.

No men were confined to their billets. If suffering from slight surgical or medical maladies which really prevented their taking part in the active training, they were given a day of kitchen police or other light duty. Everyone worked unless really sick, and if sick, was sent immediately to the hospital. If the diagnosis was not clear, no man was sent to the hospital without a thorough physical examination and a consultation with the orthopedic chief. In this way it was possible to detect men suffering from visceral ptosis, not discoverable without a thorough physical search into the relations of posture to digestive and general symptoms.

The orthopedic surgeon accompanied the men at drill each morning and afternoon, correcting the errors in marching and statics. He had to be constantly on the alert, encouraging, explaining, demonstrating to the men what was expected of them. He carried duplicate record cards and made frequent notes thereon of each man in the field.

During periods of rest between drill, the orthopedic surgeon gave talks to the men on such subjects as the care of the shoes and feet, the proper position of the body in marching, proper use of the feet, hygiene in the trenches, the fundamental purposes of the training camp. In the afternoon the men were given the only special curative exercises included in the curriculum. These exercises were reduced to the simplest. The triple exercises, i. e.: (1) Planter flexion of the toes, foot extended. (2) Hold this; twist foot in. (3) Hold (1) and (2); pull foot into dorsal flexion to strengthen the leg muscles; straight

leg raising for trunk and abdominal muscles. These exercises, coupled with certain very simple stretching maneuvers, taken by the man himself either with his hands or by standing on the edge of his bunk, were all the special treatment given. All other training was given in large groups.

Any alterations in the shoe adjustments were ordered by the orthopedic surgeon. Once each week, he rigidly inspected every man in his charge, as to the condition of his feet and shoes, noting improvement, seeing that the heels were tilted enough and in good condition, making sure the shoes were properly fitted.

The same officer coached the men in their play, attempting, with the sanitary officer, to find games in which all the men would take an active part. Among other things, the men were trained to run and jump in good form.

Three evenings each week the chief orthopedic officer gave the junior orthopedic officers instruction upon orthopedic conditions occurring among the troops, special emphasis being laid upon the methods of treatment to be followed in the Army.

The men advanced from Company "A" to Company "B," which demanded greater endurance with longer periods of drill and games, and shorter and fewer periods of rest. The transfer was made to clearly mark an advancement. In this sort of training, it was considered necessary not only carefully to grade the training, but also to encourage the men by a clearly defined progress from grade to grade, separating the grades from one another as definitely as possible.

In Company "A" the men drilled without the rifle, though they were taught the care and nomenclature of the piece, how to aim and fire, and had no long marches, while in Company "B" they carried their rifles during the morning but had no rifles or any other equipment on the march which they took during the afternoon.

From Company "B" the men who had proved their fitness to perform the drill required, who showed good form at the Saturday inspection, and who could go through the exercises required of them at the examination, i. e., a demonstration of their foot exercises, were transferred to Company "L." For this company, the program was made still more exacting. The men therein began to be more like soldiers of the line, but they were given two 10-minute rest periods in the morning's program and one half-hour lecture period. Three afternoons weekly they took a long march, and on two days a short one, followed by some active games.

In Company "M," into which they next progressed, after a similar examination, the work became still more constant and strenuous. Each morning they were given calisthenics, followed by Butts' Manual, lasting an hour, during which only short breathing spaces were permitted. The orthopedic surgeon constantly watched their position. Then followed a bayonet drill of the most active sort, lasting an hour. After another 10-minute rest period, the morning program was brought to an end by an hour of company and squad drill, and the school of the soldier. In the afternoon foot exercises were given and then the men fell in with full pack and equipment for a march of two hours, with one 10-minute rest at the end of the first hour. In this march the men were accom-

panied by their officers and the orthopedic surgeon. Silhouettes, taken of a man as he entered and as he progressed from company to company, showed in a very graphic way how he learned the proper standing posture and improved carriage, and how the round shoulders and hollow backs were made to disappear.

Between January 1 and March 20, 1918, the special training battalion received about 680 noncommissioned officers and men. From this number most of the camp personnel was recruited. One hundred and fifty men passed through the complete course of training, and were returned to their organization. They were fit when they left this camp.

It was found necessary to investigate every man who stayed longer than four weeks in any one company. In this way were culled out those who could best be used for other work. One hundred men who did not advance rapidly, or were otherwise unfit, were sent to Versailles to start the spring gardens for the Army. Twenty men unable to qualify as soldiers, but who had had experience in driving motors, were transferred to the Motor Transport Service.

In the last of March, the 350 men still in training were returned to their commands, and the special training battalion, with a small permanent personnel, was transferred to the 1st Depot Division at St. Aignan and there continued its activities until the cessation of hostilities. During the St. Mihiel and the Meuse-Argonne operations, the need of men at the front was so great that many of the men under training, who could have been made of combat fitness had there been time enough for the training, were detached from the training battalion and sent to the front for noncombat duty. At one time 1,000 men were sent to the First Army area to assist in staffing the hospitals; 1,200 men were sent at another time for the same duty; 1,000 men were sent to act as prison guards. In this way, the size of the training battalion was reduced materially and the work from then on consisted very largely in the reclassification of the men rather than the training which would have been possible had there been sufficient time.

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CHAPTER II

THE FOOT AND ITS RELATION TO MILITARY SERVICE

THE SOLDIER'S FOOT

The importance of the foot in the development and maintenance of an army has long been recognized; with the advance of civilization this problem has assumed an even greater importance. The foot of primitive man, by virtue of his means of livelihood, was trained to go and so was ready for the warpath at a moment's notice. The foot of the man of to-day, equally by virtue of his means of livelihood, is called upon less and less for active function and is used more and more as a passive support in standing, with all the consequent attendant ills of weakened muscles and faulty foot posture. It is inevitable, therefore, that the number of men unfit for military service should be greatly increased by foot disabilities and that the care of the foot should become a question for serious consideration in the training of the recruit. In the World War the difficulty of this phase of the medical service was still further increased by the urgent need for large numbers of troops, the universal draft, and the location of the theater of operations overseas.

In reviewing this work for the period of the World War, the features which seem to stand out as of especial importance and value are two—the instruction of the various branches of the service in foot requirements, and the examination of the recruits, with the prophylactic care based thereon. Beginning with but few trained workers, a system which satisfactorily stood the test of time and of varying conditions was perfected gradually and fairly early by the division of orthopedic surgery.

INSTRUCTIONS IN REQUIREMENTS WITH RESPECT TO THE SOLDIER'S FOOT

Before the World War it had been pointed out that the satisfactory solution of the foot problem is possible only through the cooperative efforts of the medical officer, the line officer, and the soldier himself.[1] Hence, from the beginning the necessity for the systematic instruction of these three classes of personnel was recognized. Obviously the plan which was finally approved [2] must be limited to the minimum requirements.

As far as the medical officer was concerned, it was evident that knowledge of the foot and its relation to the military service needed to be systematized and made available for Army use. Accordingly, a concise description of the mechanics of the foot, its disabilities and their treatment, was prepared for the Surgeon General by a few members of the American Orthopedic Association very shortly after our entrance in the war. This was first used in mimeographic form for distribution to camp surgeons. Later, it formed the foundation for the opening chapters of the War Manual of Military Orthopedic Surgery.[3] This more general information was supplemented from time to time by circulars

and special instructions covering various phases of the subject, such as the examination of the foot in border-line cases,[4] the rapid examination of the feet of recruits, and the salvaging of foot defectives. Instruction in the affections of the foot was systematically carried out throughout the training camp period as a part of the minimum amount of general orthopedic training required of all medical officers in medical officers' training camps, and also in the special clinical courses in military orthopedic surgery for medical officers assigned to the orthopedic division. With the establishment of these special courses at Camp Greenleaf and in the various special schools in university centers, the opportunity was afforded of satisfactorily instructing officers before their assignment to camp duty, in the foot requirements of the soldier. At Camp Greenleaf a course of four weeks' duration was given to a class of 25, a new class being admitted each month.[5] Not all of the men trained in this course were retained in the orthopedic group, as some finally proved better qualified for other branches of the medical service and hence were transferred. The university courses were of six weeks' duration. Later, in the perfected plan of instruction for medical officers conducted at Camp Greenleaf, a more intensive course in foot prophylaxis and treatment, as well as in other orthopedic affections, was given to all medical officers. These special courses of instruction were supplemented finally in the training camps by lectures and practical instruction by the consulting surgeons and the camp orthopedic surgeons.

Line officers and candidates for commission were required to have "a total of at least three hours of instruction in the care of the foot and its coverings" and in other simple orthopedic affections.[4] This instruction was given at first by simple talks and later by the use of moving pictures. Of the latter, three reels were prepared at the Army Medical Museum to illustrate the chapters on the foot in the War Manual of Military Orthopedic Surgery.

For all enlisted men it was prescribed that "at least one hour's practical instruction in the care of the foot and its coverings (and the treatment of minor injuries) be given once a month by the surgeon of the organization, under the supervision of the orthopedic department."[4] A course of instruction was also prescribed for selected enlisted men of the Medical Department to "be given at all training camps and other stations to fit them for rendering proper assistance in shoe fitting, the care of the feet (and the treatment of minor orthopedic affections)." As an aid in this work, a short pamphlet on Minor Foot Ailments was issued and two editions distributed.

PERSONNEL FOR EXAMINATION AND CARE OF THE SOLDIER'S FOOT

Recognizing that the examination and care of the foot was most important during the training period, the effort was made to assign for camp duty only medical officers who were known to have had orthopedic experience. The number with orthopedic training naturally soon proved inadequate and the positions then had to be filled with those trained in the special courses. In order to coordinate and systematize the work in the various camps, a corps of consulting orthopedic surgeons was next formed to fill the double function of consultation and inspection. To facilitate the work of these officers, the country

was divided into zones, so that the camps in a given zone were, as far as possible, within reasonable traveling distance of each other, and a consultant was assigned to each zone. These consulatants usually spent a week or 10 days in each camp. They reported to the Surgeon General by letter in the regular routine and personally as frequently as the distance of the zone from Washington justified.

The enlisted personnel also formed an important part of the Army foot service. A particularly useful group comprised the selected enlisted men of the Medical Department, to whom reference was made above, who were given special instruction in shoe fitting, the care of the foot and the treatment of minor orthopedic affections. A sufficient number of these were trained to permit assignments to be made to the various organizations as they were sent overseas. Assistance was also rendered by another class of enlisted men who were already trained in the treatment of minor foot ailments—the chiropodists. Those secured by transfer early in the war soon demonstrated their usefulness to such an extent that the desirability of having all qualified chiropodists who might be accepted in the draft made available for this work became evident. The necessary authority was secured and, through the cooperation of the officers of the National Association of Podiatrists in notifying the Surgeon General whenever a qualified chiropodist was ordered to camp, it was thus possible to obtain his immediate assignment to the Sanitary Corps for work under the orthopedic division. A second group which rendered a most important service consisted of the cobblers. They, too, required some training by the orthopedic surgeons in the method of making shoe alterations. In order to secure a sufficient number to care for the early work with the recruits and the later needs of the organization, the most practical plan proved to be to secure the temporary assignment of cobblers, where found, to the orthopedic department. When returned to their organizations, they were competent to care for this important detail of foot work.[6]

ESTIMATION OF POTENTIAL FOOT EFFICIENCY

The estimation of the potential efficiency of certain types of foot for military service was unquestionably most difficult not only for the medical members of the local draft boards and the camp surgeons of the earlier days of the World War but often even for the trained orthopedic specialist as well. Such an estimation calls for an adequate appreciation of the difference between foot form and foot function, an understanding of the demands made upon the individual's foot by both his occupation and his avocation, and the ability to evaluate the symptoms and signs of foot strain in its incipiency. When to this is added the confusion resulting from the frequent attitude of the individual toward the service, the attempt on the one hand to minimize or conceal past or existing trouble through his desire for acceptance and, on the other hand, to simulate the comparatively well-known symptoms of foot strain in order to escape the draft, it is not surprising that an occasional athlete was rejected because of a low arch, while many individuals with normally high arches but with potentiality weak feet were accepted, nor even that many foot defectives were sent overseas.

FOOT EXAMINATION

The recognition and correction of remediable foot defects, the segregation of recruits requiring a more gradual system of training, and the elimination of any with actual disability who may have been inadvertently passed by the draft boards are among the first important details to which attention must be given at the time of the induction of the recruit into the service. This was most readily accomplished in the casual detachment or depot brigade, where the recruit was first quartered on entering the service. In case he was transferred to a large camp or cantonment, it could be carried out satisfactorily in quarantine barracks, if he was first sent there, but if sent directly to his organization, arrangement had to be made for the examination through the regimental commander and care taken to interfere as little as possible with the work of the organization. One obstacle to success in handling the work in the casual detachment or depot brigade was that there might be no issue of equipment until the recruit reached his permanent assignment and hence shoe alterations could not be made. The attempt to obviate this difficulty by attaching to the man's service slip a separate record of the examination with recommendations as to alterations was not entirely successful, owing to these separate records being lost or thrown away through failure to recognize their importance.[6]

In the beginning, as was to be expected, many difficulties were encountered. The number of foot defectives was relatively larger among the early recruits, due in part, at least, to the inevitable lack of experience of the medical members of the local draft boards with orthopedic principles and to the patriotic desire to ensure that no shirkers escaped. When these early recruits reached camp, the medical service was as yet too imperfectly manned and too insufficiently organized to carry out routine examination and treatment in the most efficient manner, and even their importance was not always fully recognized by all officers. The supply of shoes was frequently insufficient to enable the men to be fitted promptly and properly. Finally, an efficient method for handling those presenting the more severe types of disability and those suspected of malingering had not yet been instituted. With increasing experience these difficulties tended gradually to grow less or disappear entirely, and a system was perfected which proved most satisfactory.

Routine Method of Rapid Examination

With large numbers of recruits a method of examination is required which is both rapid and accurate. Various methods were tried in the different camps, of which the following may serve as an example:[7]

The men are examined standing on a table. The table should be high enough to come to the shoulder level of the seated surgeon. The man walks across the room and mounts the table, standing in front of the examiner. The way he walks across the room and the way he mounts the table are an excellent index of the functional ability of his feet. By inspection the surgeon notes visible defects, then putting a hand on each foot the position of the scaphoid is noted with the thumbs. The toes are pushed up next and any rigidity noted. Then the man is instructed to give his left foot to the examiner, holding the knee straight. The examiner's left explores the heel for any abnormality; the right hand grasps the forefoot and tests the functions of the sub-astragaloid and midtarsal joints. Lastly, the forefoot is pushed up and the condition of the ankle joint and the tendo Achillis is noted. In this

position the sole of the foot is inspected for callosities. The right foot is examined in the same way, except that the examiner reverses his hands.

With the use of this system, it was found possible for two orthopedic surgeons and four clerks to examine and record the results of 100 foot examinations per hour.

ANALYSIS OF FOOT DEFECTS FOUND IN RECRUITS

For practical consideration the foot defects may be divided broadly into four groups: (1) Defects correctible by simple shoe alterations; (2) those usually producing disability for full military duty; (3) those correctible by operative means; (4) defective muscular strength or development.

The Surgeon General stressed the importance of taking especial care in the examination of recruits to detect those slighter deviations from the normal in foot form and posture which are potential sources of disability. Pronation, flattening of the longitudinal arch, limitation of dorsal flexion, flattening of the transverse arch, and cavus, existing in a degree insufficient to produce disability under the ordinary demands of civil life, are naturally aggravated and may become exciting causes of foot strain under the arduous demands of training and the increased weight imposed by the pack. Of all the orthopedic foot work carried on during the training period, the prophylactic correction of these defects was undoubtedly productive of the greatest good.

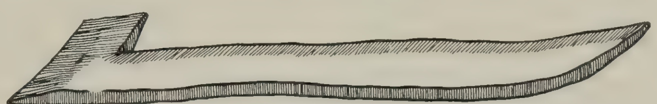

FIG. 38.—Tomahawk wedge, the standard shoe alteration for ankle valgus, to shift weight bearing to the outer side of the foot; supplied in three thicknesses. (This and figs. 39–41 are from Rich, E. A.: Static Defects of the Feet. *J. A. M. A.*, 1918)

Pronation, alone or associated with abduction of the forefoot, and flattening of the longitudinal arch, when there is no loss of flexibility and no structural change, are simple postural deviations which were most commonly found in those whose occupation had been either sedentary or one requiring prolonged standing. The free use of the toes permitted by the Army shoe, with the active thrust from the forefoot soon acquired in training, tended naturally to the permanent correction of these defects, providing the fatigue incident to the early days of training did not aggravate them to a degree where they became pathological. Assignment to special squads for more gradual training and the use of corrective exercises were of definite advantage in the more pronounced cases. In most, however, the simple wedging of the heel on the inner margin, or of both heel and sole (figs. 38 and 39), to a degree

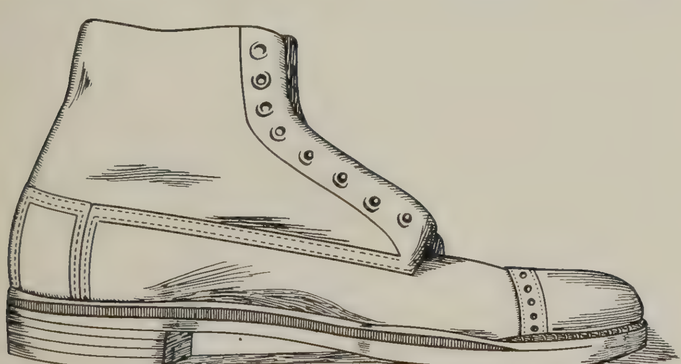

FIG. 39.—The tomahawk wedge in place

proportionate to the amount of the deviation, fully met the indications. Limitation of dorsal flexion, or "short heel cords," of moderate degree, required merely a slightly higher heel.

In simple flattening of the tranverse arch and other defects of the forefoot, the anterior heel (fig. 40) was found to meet all needs most admirably. As used in the British Army, the anterior heel consisted of a simple cleet of leather fastened to the outside of the sole just back of the ball.

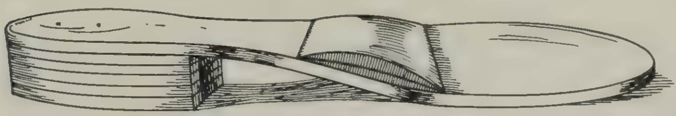

FIG. 40.—Anterior heel in position

In our camp experience, however, it was found more satisfactory to place the piece of leather forming the heel between the layers of the sole, as in this position it could be used even with a thick sole and also did not wear down as quickly.

Cavus, or contracted foot, is a type of foot form of much more frequent occurrence than is generally realized. It was found to be "exceedingly common among our southern troops, especially from the Delta States."[8] The greater strain thrown upon the metatarsal heads by the reduction in the weight-bearing surface of the sole through the high arch is greatly increased in military life by the active function required of the forefoot and by the burden of the pack. Under these conditions even mild degrees became potential sources of serious disability. In order to fit the "cavus foot" the shoe must have a high shank, and as cavus is more frequent in the slender type of foot a narrow width is necessary. The Army shoe, ideally as it is adapted to the great majority of feet, does not meet the requirements of the foot with cavus. In the milder degrees, however, it was possible to alter it so as to overcome the difficulty very satisfactorily by a slight modification of the anterior heel just described, the leather insert being simply made longer so as to extend farther back toward the heel (fig. 41).

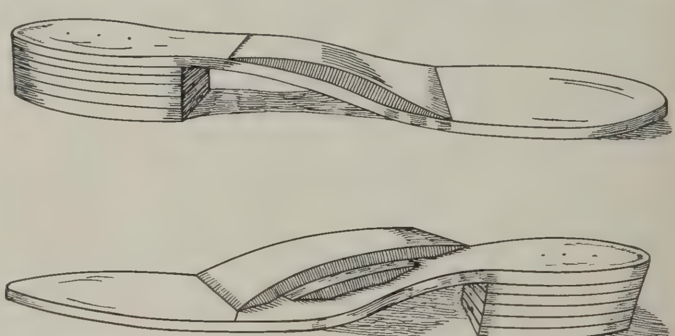

FIG. 41.—Position of rocker shank on the outer sole. The alteration for minor degrees of cavus. With more extreme types the rocker shank of two or more thicknesses of leather is demanded to redistribute weight bearing. The lower illustration is diagrammatic of positions of leather inserts when multiple

For the more severe cases additional pieces of leather were inserted or a similar elevation was attached to an insole and fastened inside the shoe. With a little training the company cobblers soon became very proficient in making these alterations and were able to finish the individual ones in a few minutes.

When the foot was so changed that the shoe alterations mentioned were insufficient to correct the defects, it was found possible in only a relatively few cases among white troops to make the individual fit for active overseas service. The conditions which proved thus disabling were "flaccid flat feet with marked

abduction and eversion, rigid or spastic flat feet, rigid arthritic or post-traumatic feet, marked cavus, pes varus or valgus following fracture, extreme hallux valgus, with painful bunion or metatarsalgia, hallux rigidus, amputation, partial amputation or severe derangement of the joints of the great toe, and proved exostosis of the undersurface of the os calcis."[7] In negro troops these conditions differed somewhat. The foot of the negro possesses greater flaccidity, which is compensated for by greater muscular development, and many negroes who had no subjective symptoms were found with flat feet associated with abduction and eversion.[7] In the earlier months of the war it was a difficult matter to handle properly these cases with disabling conditions, but with the establishment of the foot camp, and later of the developmental battalion,[9] a way was provided for testing them out and arranging their assignment to noncombat duty.

The operative results of most abnormalities of the foot, such as hallux valgus contracted foot, hammertoe, had been long known to be generally certain and satisfactory, not only in civil life but also in the Army during peace time. Hence, after we entered the war it was felt that conservation of man power would be promoted by operating on all such conditions found among the recruits. It was soon recognized, however, that equally good results could not be secured under war conditions. The probable difference in the mental attitude of the drafted recruit, the arduous work which the operated foot was soon called upon to perform, and the comparatively short period which could be devoted to convalescence were apparently the main factors in causing this difference. This policy, ideal as was its conception, proved economically a failure, and hence a circular letter was issued by the Surgeon General, November 12, 1918, advising against such elective operations.

Recruits with insufficient muscular strength apparently constituted, everything considered, the most troublesome group. They were of two kinds—those in whom the strength was below the requirement owing to excessive weight; those with insufficient muscular development. The first class readily responded in most instances to the rigors of training and required merely the corrective shoe alterations and a more gradual method of training. A large proportion of men with insufficient muscular strength also responded to the same measures. There still remained a considerable number, however, whose muscles could not be brought up to the strength required for active duty, even when detailed to special squads for preparatory training. This is not surprising when it is considered that not only had large numbers of them been engaged in sedentary pursuits, with little or no opportunity for outdoor activities, but also that in many a constitutional or even a congenital cause for the defective development existed. Hence, its correction in the comparatively short period that was available, however scientifically training might be carried on, could not be expected. The recognition of these muscularly unfit was naturally difficult for medical officers who had had no experience with the demands made by an active military campaign. So, in the efforts at conservation, some of these border-line cases were allowed to go overseas. Another class of this group, in which the muscular strength proved insufficient, but for an entirely different reason, comprised recruits assigned to fill vacancies in regiments partly or completely trained. Under these conditions it sometimes happened that feet which would

have proved entirely adequate under the ordinary method of training broke down because the muscular strength was not sufficient to meet the great demand suddenly made upon them.

SUMMARY OF THE ESTIMATION OF FOOT EFFICIENCY

In view of the importance of the estimation of foot efficiency for military service, a summary of the chief points brought out in our camp experience seems desirable. Since the abnormalities of the foot which have been found disabling are clearly defined in Army Regulations, only those deviations from the normal which may or may not cause disability need be considered.

Experience shows that this estimation must be based on a study of the form and the function of the foot and the development of the muscles by which it is activated, careful consideration being given also to the relation between the work previously required of it and that demanded by active military duty.

In considering foot form, the height of the arches alone has little significance. Considerable difference exists within normal limits, due to race, the character of the work done, and the type of foot coverings worn. Between the high arch of the decendants of the Spaniard and the low arch of the negro there is marked variation, and yet the two may be equally efficient. The arches of one who has done heavy work and those of the athlete, particularly when the work or play was begun early in life, are relatively low and the forefoot spread, and yet both have been trained to withstand great strain. Similarly, the foot which has never worn a shoe, as occurs among our mountain people, presents a lower, broader aspect, although its strength is beyond question. Pronation with abduction of the forefoot and eversion (toeing out) may be present in moderate degree as purely postural defects, and, provided the foot is flexible and the muscular development good, they are of importance only as far as prophylaxis is concerned. Only when these deviations of slighter degree are complicated by impairment of flexibility or poor muscular development, or when they are present in more than moderate degree, are they likely to prove disabling.

It is the function of the foot, however, on which the final determination in doubtful cases depends. Foot form is necessarily always of secondary importance to foot function. Hence, in the last analysis the essential requirements of the soldier's foot are normal flexibility and good muscular development, since without these normal function is impossible. Loss of flexibility even in a single joint or in a single direction must always be regarded with suspicion and its cause determined. Moderate limitation of dorsal flexion alone, however, is often the result of simple adaptive shortening of the calf muscles from the constant wearing of high-heel boots and responds readily to prophylactic heel alteration. Limitation of motion from old fractures or arthritis, even when present in only slight degree, is usually disabling, while loss of flexibility in more than slight degree from any cause is practically always so. The accurate evaluation of the potential muscular strength in doubtful cases is perhaps the most difficult factor of all in the estimation of foot efficiency. When poor muscular development exists in feet presenting deviations from the normal of sufficient degree to act as potential causes of disability, the decision is relatively simple. But

when the poor muscular development exists alone, it is by no means so easy. In the latter instance all the factors bearing on the condition must be considered—its cause and duration, that is, whether congenital or acquired, and, if the latter, whether due to constitutional defects, disease or simple lack of exercise, the attitude of the recruit toward service, and whether provision can be made for graduated training, are all of importance.

THE FOOT CAMP AND THE TRAINING BATTALION

In our early camp experience it was a difficult matter to handle satisfactorily the doubtful cases of defective feet and those which had broken down in training, and to determine definitely the ones able to meet the demands made upon the soldier. This difficulty was solved by the formation of a special organization, called the foot camp. Apparently this plan was developed about the same time in several camps. The men were assigned to this camp on special detail. Lists for admission and discharge were made out twice a week. When the development battalion was formed, the foot camp naturally became part of it.

Men were examined in groups within 24 hours after admission to the camp, the shoe measurements being verified, shoe alterations made, and the drill class suitable in each case designated. A division into three classes proved most convenient—no drill, drill, and heavy drill. Foot exercises, performed barefoot, were given all the men at setting-up drill, those in no-drill class receiving two half-hour periods daily and the others one. The no-drill class was given foot exercises and light detail, the drill class infantry drill, graduated to its ability, and the heavy drill class went on marches in addition to performing its other work.

Three types of cases were encountered in the foot camp—the real defectives, the timid, and the malingerers. Men with actual remediable defects responded satisfactorily to the system carried out. The timid likewise usually responded to the effect produced by the careful examination, the assurance that there was no serious trouble, and the confidence acquired through the graduated work. The malingerers could soon be recognized in the foot camp and were then assigned to the hard and disagreeable tasks. Privileges were granted only to men doing heavy drill, it being explained to the others that since their foot condition was such that they could not do full duty, it was inadvisable for any extra strain to be put on the feet. This method proved a great incentive to work.

By this system it was possible to test the men out thoroughly and to return the physically fit for duty to their organizations, the others being disposed of otherwise, as the conditions warranted. Out of 822 men handled in the foot camp in four and a half months, 614 were returned to their organizations, 447 of these going back to full duty, while 167 were recommended for domestic duty or discharge.[7]

THE ARMY SHOE

The standard shoe issued by the Army during the World War proved to be all that could be expected of any shoe. It was found that practically 98 per cent of feet could be satisfactorily fitted with this shoe.[10] Shoes on similar lines but with a more marked "inflare" were also used at times, but

proved less suitable; for, while the feet of the younger soldiers would adjust themselves to these more pronouncedly curved shoes, those of the older ones could not, with the consequent development of corns on the toes where they pressed against the outer border of the shoe.[6]

Our camp experience as a whole merely verified the recommendations already made [1] in regard to the fitting and care of the shoe. The difficulties encountered in shoe fitting were not due, therefore, to the shoe itself but to an insufficient supply, irregularity in the time of issue, lack of men properly trained in shoe fitting, and the attitude of the soldier himself. These difficulties, too, had previously been recognized and fully covered in the report of the Army Shoe Board. An insufficient supply of shoes is to be expected in the early part of any war, particularly when large numbers of men are being called for service. When the supply of shoes is adequate, however, an early and a uniform time of issue is of distinct advantage. It was found that when the shoes were issued within the first three days after the men were inducted into the service, the shoe alterations could be made before the period of quarantine was past. With the definite directions for shoe fitting given in Army Regulations, any reasonably intelligent soldier can soon be taught the necessary skill, and the chief consideration is rather whether he possesses the essential qualities of responsibility, patience, and the ability to handle men. It was possible soon to train sufficient men for all needs. The greatest obstacle to successful fitting was after all the attitude of the recruit himself. Many with poorly developed feet, and without experience in the demands made by outdoor pursuits, had no appreciation of the difference in shoe requirements and so, through ignorance, and also frequently through pride, used every expedient to avoid wearing shoes of the correct size. As the recruit developed into the soldier, this obstacle largely disappeared.

The little that our experience added to our knowledge of the Army shoe was limited largely to the method of making the alterations for the correction of postural and other defects.[8] To facilitate the work of making these alterations in the camps, the necessary pieces for insertion were furnished as a part of the cobbler's outfit and supplies.

The effect of the Army shoe on the appearance and development of the foot and in the correction of many of its defects, particularly those of the forefoot, was most striking. Of the minor foot ailments, corns gradually disappeared, bunions ceased to be painful, crooked toes tended to straighten, and ingrown nails gave no further trouble.[11] Anterior arch troubles, which are promoted by the distortion and constriction of the forefoot caused by improperly shaped and incorrectly fitted shoes, usually responded to the free use of the forefoot permitted by the Army last, aided, if necessary, by the anterior heel.[10] Similarly, the normal use of the foot as a whole resulted in a marked development of its tissue and gave it "an appearance of health commensurate with the work it had to do." [11]

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CHAPTER III

FRACTURES CAUSED BY PROJECTILES

In Chapter III of the volume on general surgery, statistical data concerning fractures may be found. Only brief references to the relative incidence of such injuries are made here.

As a measure of the importance of fractures in military surgery, it may be stated that among the 153,527 battle injuries (excluding trauma by deleterious gases) in the American Expeditionary Forces, there were 25,272 patients (16 per cent) with fractures, the major portion complicating gunshot wounds.[1] When consideration is taken of the varied character of such fractures, their almost invariable infection, and the attendant difficulties to which they gave rise in transportation, it may readily be seen that they presented ever-varying problems to the military surgeon.

PRIMARY MANAGEMENT

The primary management of fractures accompanying gunshot wounds, as has been told in Chapter I, was a function of the Medical Department of a tactical division of troops. To effect this the equipment was set up in places as favorable as possible to the successful operation of a plan of evacuation, and in as close contact with the troops actually engaged in fighting as the military situation allowed. The precepts of such management, as outlined in the Manual of Splints and Appliances,[2] are: (1) The application of first-aid, splints, and dressing, to the wounded soldier where he falls. (2) The transportation of the wounded soldiers to an aid post—usually by litter carry. (3) The treatment of shock and hemorrhage and proper splint and dressing application at an aid post. (4) The transportation of the wounded soldier to a hospital where proper facilities make it possible to carry out surgical treatment by motor or animal-drawn ambulance.

The following supplies in splints and splinting material were to be carried by the various medical units and detachments in quantity sufficient to meet the casualties of 24 hours' severe combat:

Splints and splinting material carried by Medical Department units and detachments

	Splint distribution for regiment of Infantry			Total for each regiment of Infantry	Splint distribution for each regiment of Artillery		Total for each regiment of Artillery	For each ambulance company	For each motor ambulance	For each field hospital	For each battalion of Engineers and each noncombatant unit	Total for a division
	For each advance Infantry aid post	For each Infantry battalion aid post	For each Infantry regiment aid station		For each battery of Artillery	For each Artillery battalion aid post						
Straps and buckles	2	6	6	36	2	3	[1] 12–15	25	2	25	4	406
Snowshoe trench litter	------	------	------	------	------	------	--------	2	------	2	------	10
Thomas-half ring leg splint (Blake-Keller)	1	6	6	36	1	3	12–15	25	1	25	4	400
Thomas hinged arm splint (Murray)	1	6	6	36	1	3	12–15	25	1	25	2	400
Cabot posterior wire splint	1	6	6	36	1	3	12–15	50	1	30	4	450
Wire ladder splint	2	12	12	56	2	6	[1] 24–30	100	------	50	12	1,000
Wood splint assorted	1	6	6	36	1	3	12–15	50	------	25	2	450
Long Liston splint	0	0	0	0	0	0	0	4	------	4	0	20
Litter bars	0	10	6	36	1	6	15–18	50	1	25	2	400
Triangular bandages	6	24	24	200	6	12	60–72	200	------	200	24	3,000
Cotton (wadding) } Rolls (batting) }	0	4	4	16	0	0	4–6	25	------	25	10	350
Muslin bandages 4-inch and 6-inch assorted	6	24	24	120	6	12	60–72	200	------	200	12	1,500
Z. O. adhesive 2½-inch rolls	1	6	6	36	1	1	[1] 12–15	30	------	30	6	400
Wire foot supports	0	10	6	36	0	3	15–18	50	------	50	2	500
Wire-gauze rolls	0	0	0	0	0	0	0	0	------	25	0	100
Sinclair's glue	0	0	0	0	0	0	0	0	------	½ kilo.	0	2 kilos.
Adjustable traction straps	1	6	6	36	1	3	12–15	25	1	25	4	400
Hand and wrist splint	1	3	3	18	1	2	6–8	15	1	15	2	250

[1] The first column is for regiments of 2 battalions each; the second for those of 3 battalions each.

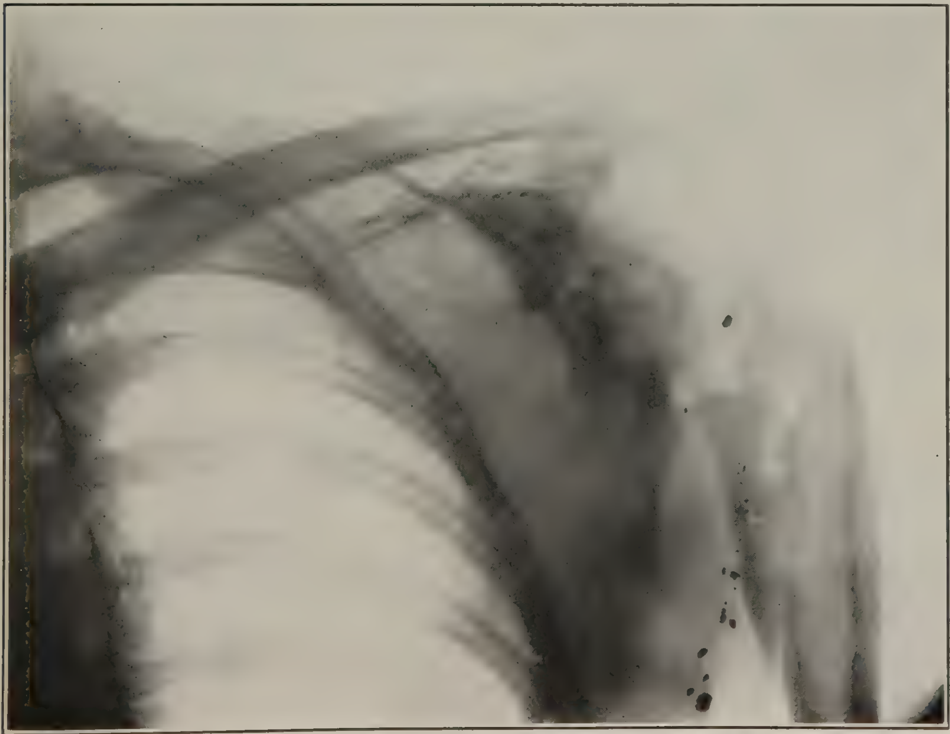

FIG. 42.—Detrsuction of the head of the humerus, outer portion of the clavicle, head of the scapula, and comminuted fracture of the upper portion of the shaft of the humerus by rifle missile. Fragments of the shattered missile shown in the soft tissue

As carried out in the American Expeditionary Forces the primary management of all fracture cases with reference to splinting was very similar in the front lines and may be outlined in a general way. The object in each case was to get the wounded man back to the evacuation, or mobile surgical hospital in condition for whatever operation was necessary, and, in order that he might arrive thereat in condition for operation, it was necessary, to minimize shock, to protect him as much as possible from cold, pain, and hemorrhage. This was accomplished by the following routine: After a man with a fracture had been removed to the first available shelter, a splint was applied, the wound

FIG. 43.—X-ray picture, showing fractured clavicle and lodged missile in the outer end of the clavicle

was exposed, and the dressing applied to the wound after the control of hemorrhage; antitetanic serum and morphine were administered, whereupon he was ready for transportation back to the advanced ambulance dressing station. As soon as possible after arriving at the ambulance station, the dressings were inspected as to hemorrhage, the limb as to swelling; the splint was adjusted if necessary, and the man's general condition observed. He was given a hot drink and, if cold, was warmed either by extra blankets or by placing the litter over a Primus stove. He was kept at the ambulance station long enough to get thoroughly warmed before being placed in the ambulance for the triage or operating station.

FIG. 44.—Fissure fracture of the greater tuberosity of the humerus by shell fragment, which is shown lodged

FIG. 45.—Comminuted fracture of the upper portion of the diaphysis of humerus, with moderate dispersion of bone fragments

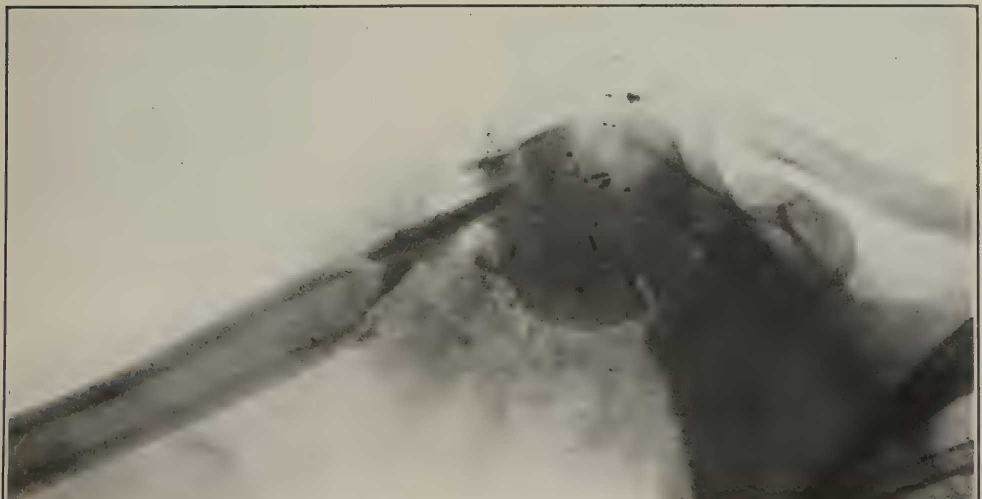

FIG. 46.—Fracture of upper end of diaphysis of humerus by rifle missile, with much loss of bone. Fragments of the missile are shown dispersed in the tissue about the head of the humerus

The medical personnel of the combat troops was informed as to the importance of getting a gunshot fracture case back to the operating station as soon as possible so that the infection might be better controlled by early débridement, and that an important factor in keeping him comfortable on the way back was proper splinting of the fracture. Therefore, little attempt was made in the

FIG. 47.—Wound of the upper portion of the shaft of the humerus. The fragments of bone are large and but little separated, though there is considerable displacement

FIG. 48.—Fracture of middle of shaft of humerus by shell fragment; moderate separation of bone fragments. Shell fragment, relatively large, lodged

forward area to cleanse the wound; it was impossible to do so properly, and by merely applying the dressing, more attention could be given to the application of the splint and control of hemorrhage.

SHOULDER

Gunshot wounds of the shoulder, either with or without fracture of the scapula, clavicle, or upper portion of the humerus, often were associated with

chest injuries, and frequently it was not possible to splint these cases. The large triangular bandage was applied and the arm pinned securely to the side.

UPPER EXTREMITY

Humerus and Forearm

It soon proved that the hinged traction arm splint was best adapted for arm and forearm fractures in the forward area, the reason being that with the

Fig. 49.—Wound of diaphysis of humerus by rifle missile, with wide separation of bone fragments

Fig. 50.—Compound, comminuted fracture, lower end of humerus, result of deformed rifle missile

hinged arm splint, the arm could be carried at the side—an advantage for litter cases. Another important factor was that, because they were more compact, these splints could be carried forward much more conveniently than could the full ring splints. Some difficulty was experienced at first in securing traction in the arm splints, or rather too much traction was attempted. Since

a hitch or tie of any kind around the wrist often produced excessive swelling of the hand and pressure sores, it proved necessary to forbid its use, and instead it was suggested that adhesive plaster be applied to the forearm and wrist for extension. Experience proved, however, that it was not necessary to have any great amount of traction, and that the splint could be held in place by a bandage through the ring passed over the opposite shoulder. The slings, in which the arms were to rest, were made of ordinary muslin or flannel bandage, and were placed rather far apart. The wire-ladder splint or flexible board was used for support, and the arm was firmly bandaged to the side bars of the splint. In many instances, however, the Jones humerus traction splint was used in the forward areas; it was better adapted for walking cases than for litter cases. When the humerus was fractured traction was made by bandaging the forearm firmly to the splint, countertraction being secured by a bandage over the opposite shoulder, thus holding the ring well up in the axilla, wire-ladder or board splints being applied over the dressing and the arm bandaged to the splint. As the use of adhesive plaster required the removal of too much of the clothing, resulting in undue exposure, it was not practical for arm traction.

FIG. 51.—Rifle missile injury of shafts of ulna and radius, and indirect fracture of lower end of shaft of humerus

In fractures of the upper portion of the forearm traction was obtained by a hitch placed on over the clothing of the lower third of the forearm and tied to the end of the splint, countertraction being secured by bandaging the arm to the upright side bars and securing the splint by a bandage through the ring across the opposite shoulder. (No bad effect was noted from the hitch in flexed arm splints.) Support by means of wire splinting was used and the arm bandaged.

Wrist and Hand

For fractures of the wrist and hand, wire-ladder splinting, plain boards, or the Jones "cock-up" splints were used. In all these cases, rather firm bandaging was practical over a large dressing which controlled hemorrhage, obviating the necessity of a tourniquet in cases of bleeding at the wrist or in the hand, and better immobilizing the fractures.

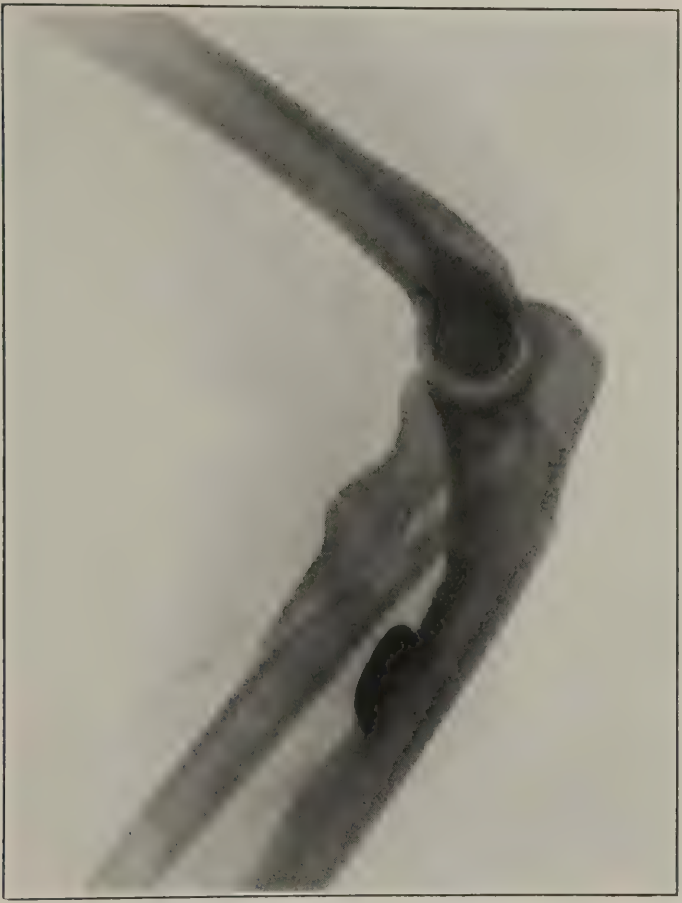

Fig. 52.—Fracture of upper ends of ulna and radius by rifle missile. There is considerable displacement of the fractured shaft of the radius. The lodged missile shows the common form of deformation peculiar to the "spitz" or pointed bullet. This bullet frequently tends to lodge when it strikes cancellous and compact bone tissue

LOWER EXTREMITY

First-Aid Splinting

For first-aid splinting of the lower extremity the Thomas half-ring leg splint was applied for all fractures from the pelvis to the ankle. After its adjustment and the injured soldier was placed on the litter, this splint was suspended from the litter bar, otherwise it tended to be displaced and traction

was lessened. The Thomas half-ring splint had advantages over the full-ring splint in the divisional areas; it is lighter, more readily transportable in numbers because it requires less space, and is not so apt to be broken during shipment as the full-ring splint.

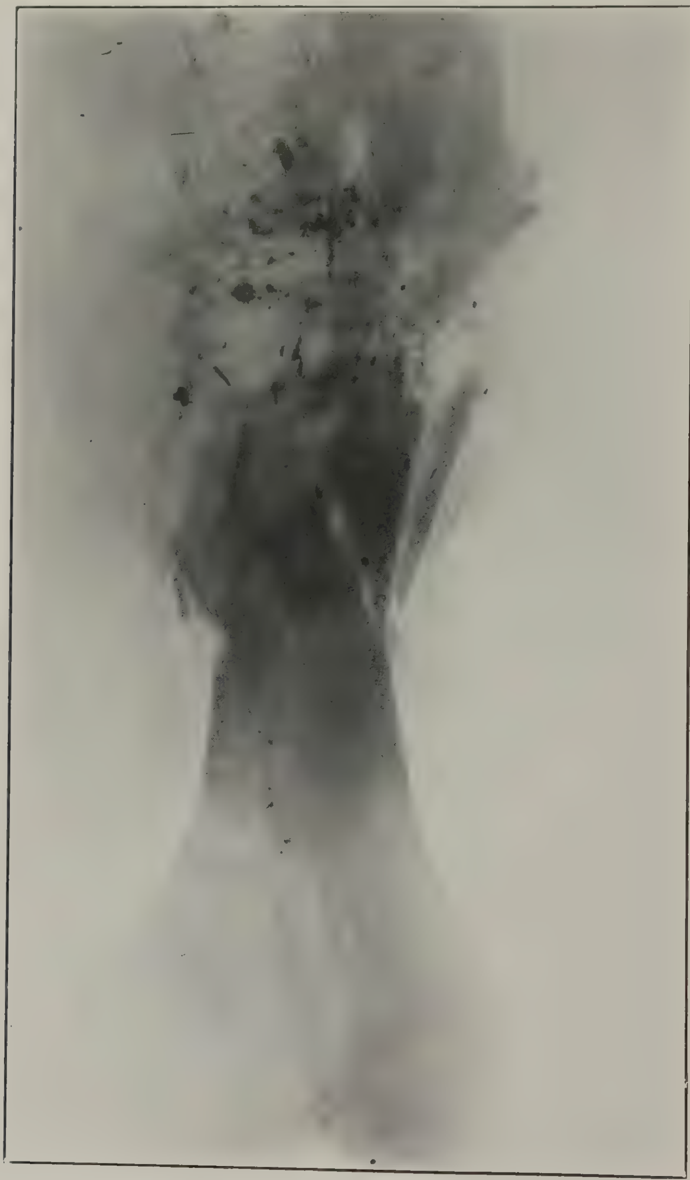

FIG. 53.—Fracture of shaft of femur, juncture of middle and lower thirds, by rifle missile, showing explosive effect of missile striking compact bone. Comminution is extensive; the bone fragments are widely separated. Missile fragments are dispersed in the soft tissues

In applying the splint to secure the needed traction, three important points must be borne in mind: (1) The proper pressure upon the tuberosity

of the ischium. Of course, in getting traction, one must have traction of the foot and countertraction at the head, and the countertraction is obtained by the pressure of the ring of the splint on the tuberosity of the ischium. One of the

FIG. 54.—Same as Figure 53, taken three months after the receipt of injury, showing progress of repair, such as callus formation and sequestration. There is marked angulation of upper and lower fragments

greatest faults was to allow the ring to slip up over the tuberosity, thus losing all traction. (2) The traction anklet. The men had a great tendency to remove the shoe. This took time, it hurt the man, and there was no excuse

for it. The canvas anklet, which was developed and carried on every splint, was made to fit over the field shoe, and if the shoe was not left on one had to use the foot. Removing the shoe was one of the common mistakes made in

FIG. 55.—Fracture of shaft of femur by shell fragment, shown lodged. There is some displacement but little or no comminution

the application of this splint. The shoe would be removed, no cotton padding would be used, consequently the anklet did not fit; it caused undue pressure on the foot and shut off the circulation. (3) The method of supporting the limb. The simplest and quickest way to apply the Thomas half-ring splint under field

conditions is with three triangular bandages. These are folded as one would fold a cravat, about 4 inches wide, and one of them is applied behind the middle of the thigh. It is passed through under the thigh and over the two side bars and then down around the back of the thigh again, crossed and tied in front, thus providing support from behind and in front. In the same manner one is applied at the middle of the leg and at the knee. This is all the support needed; already the dressings have been applied, there remains then but the necessity for a circular bandage around the splint and the leg. Needless to say, it is necessary to support the leg on the litter bar.

FIG. 56.—Rifle bullet wound, lower extremity, femur. Because the missile was nearly spent there has been no marked destruction of bone

FIG. 57. Same as Figure 56, viewed from front

The method of first-aid application of the Thomas splint, practiced in drilling the men to familiarize them with the use of the splint, was the same as that taught in the school of instruction for the medical services of the British First Army. The full text is as follows:

DRILL FOR FRONT-LINE APPLICATION OF THOMAS SPLINT

The Thomas outfit consists of: Stretcher on trestles. Blankets, three. Primus stove. Thomas splint (largest size). Reversible stirrup (Sinclairs). Suspension bar. Flannel bandages (6 yards), three. Triangular bandages, four. Dressings. Safety pins. Gooch' splinting (10 by 6 inches and 8 by 6 inches).

Personnel required: Operator. No. 1 assistant. No. 2 assistant (if available). When not in use the splint is kept hung up. The five slings of flannel bandages are rolled around the inner bar of the splint, the leather is kept soft by saddle soap, and the iron bars are kept smeared with vaseline.

INDICATIONS OF FRONT-LINE APPLICATION

1. For all fractures of the thigh bone, except where there is an extensive wound in the upper part of thigh or buttock, which would interfere with the fitting of the ring.

2. In severe fractures about the knee-joint or upper part of the tibia.

3 In certain cases of extensive wounds of fleshy part of thigh.

Fig. 58.—Compound, comminuted fracture, lower extremity of femur, with marked dispersion of fragments, resulting in a destruction of both condyles, due to a laterally perforating rifle missile

DETAIL OF THOMAS' SPLINT DRILL

I. Warming (*Réchauffement*). On the word "One."—The stretcher placed on trestles, with a Primus stove beneath, is prepared as follows: The first blanket is folded lengthwise into three, two folds lie on the stretcher, one hangs over the side. The second blanket is arranged in the same way, one fold hanging over the other side of the stretcher.

The patient is now placed on the prepared stretcher and lies on four folds of blanket; the two folds hanging down form a hot-air chamber. The third blanket is placed across the patient's chest, while the splint is being applied.

FIG. 59.—Pistol ball wound, head of tibia, showing effect of low-velocity missile on spongy bone. Note tract of missile

FIG. 60.—Same as Figure 59, viewed from inner side

FIG. 61.—Penetration of upper extremity of tibia by rifle missile, with slight detachment of fragment of shaft

FIG. 62.—Same as Figure 61, viewed from front

II. Extension. On the word "Two." No. 1 assistant stands at the foot of the stretcher facing the patient and opposite the injured limb. Grasping the heel of the boot with his right hand and the toe with his left, keeping the arms straight, he exerts a steady pull, thereby

FIG. 63.—Perforating wound of upper portion of shaft of tibia by rifle missile. Much loss of bone shows, but there is little displacement of the bone fragments

producing the necessary extension. No. 2 assistant supports the injured part above and below the fracture.

III. Clove hitch. On the word "Three."—To form the clove hitch the operator takes a length of 9 feet of flannel bandage. Holding it in the left hand by its mid-point, he grasps the center of the left half with his right hand, palm to the right, and makes a loop which is

carried up and passed behind the left hand, thus forming a clove hitch with a diameter of 10 inches.

This is applied over the boot with the short end on the outer side; the long end is carried under the instep, up and through the loop around the ankle. The two extension bands thus produced are ready to be attached to the splint later on.

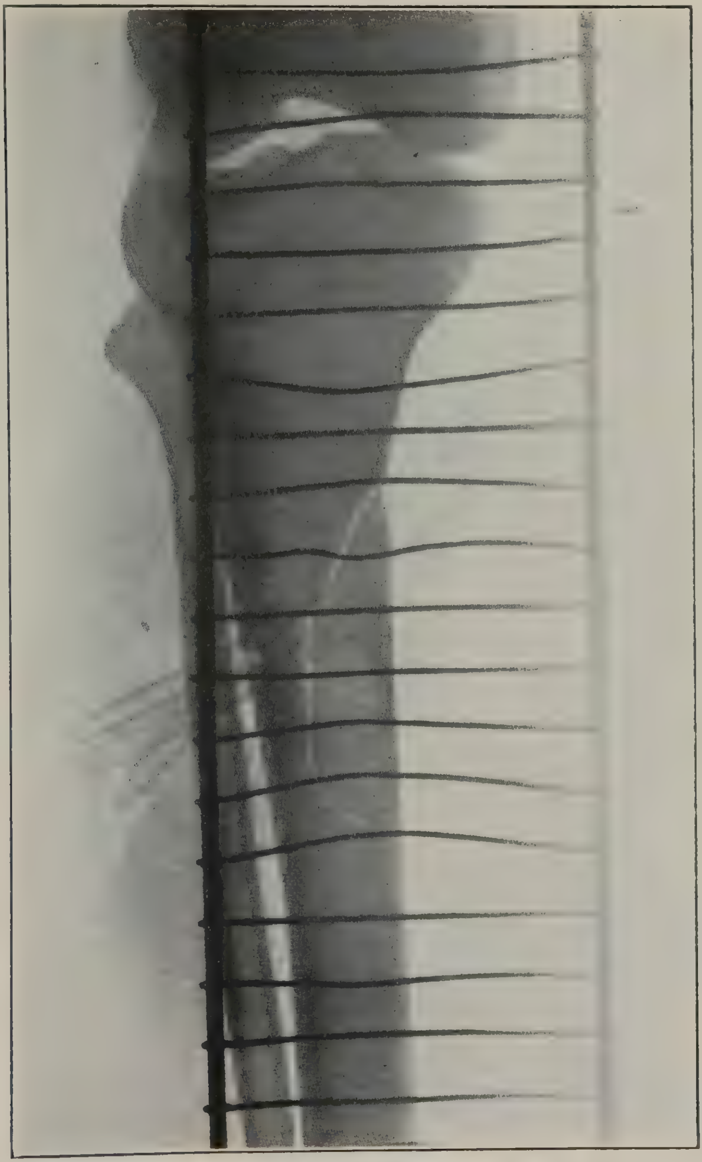

FIG. 64.—Same as Figure 63, viewed from the back

IV. Splint. On the word "Four."—The operator threads on the splint. No. 1 assistant removing and reapplying upper and lower bands alternately to allow the ring to be passed over the foot. The splint should be pushed up under the buttock as far as possible, care being taken to keep the notched transverse bar horizontal. No. 2 assistant, as before, steadies the thigh.

V. Fixation of leg. On the word "Five."—1. The extension bands of the clove hitch are tied around the notched bar at the end of the splint as follows: The outer band is passed over and under the bar, round the notch, drawn taut, and held over to the opposite side. The inner band is passed under and over the bar, then also round the notch where it crosses the first band and prevents its slipping. The two are finally tied off by a half bow.

2. The middle flannel sling is tied behind the knee which is held partly bent by No. 2 assistant.

FIG. 65.—Compound, comminuted fracture of shaft of tibia, showing typical "butterfly" arrangement of fragments

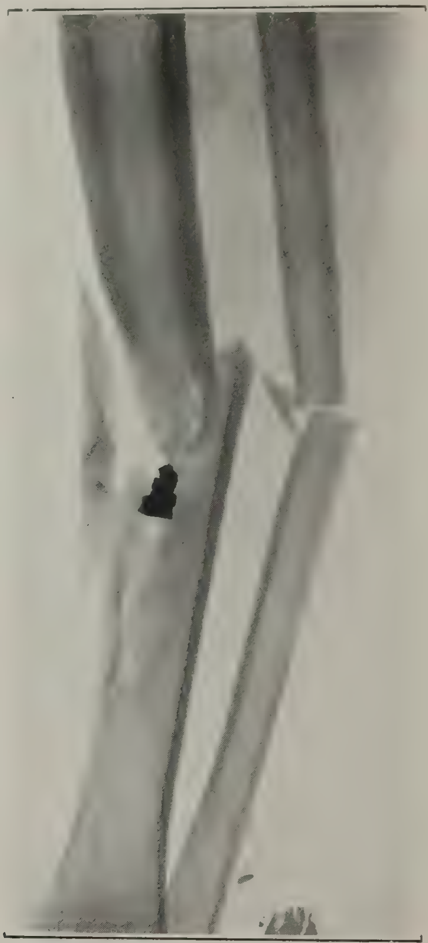

FIG. 66.—Fracture of middle of diaphysis of tibia, caused by shell fragment. Indirect fracture of fibula. Shell fragment shown lodged

3 and 4. The slings behind the ankle and calf are tied so that the leg rests in a shallow trough, with its center on a level with the long bars of the splint.

5. To prevent the leg rising off the splint, a narrow fold bandage is placed across the leg just below the knee; the ends are carried down between the leg and splint and brought up outside the bars and tied off in front of leg. The lower limb is now firmly fixed in a position of extension and it may be moved freely without causing pain to the patient or damage to the injured part.

VI. Dressing wound of thigh. On the word "Six."—The wound is exposed by cutting away the overlying portion of trousers on the front or back of the thigh, and the dressings are then applied.

VII. Gooch splints and bandages. On the word "Seven."—The Gooch splints are now applied. The short piece is placed behind and secured by tying the remaining two slings The long piece is placed on the front of the thigh, care being taken to avoid pressure on the knee cap. The whole is now retained in position by two narrow-fold bandages carried round the thigh outside the bars of the splint.

VIII. Stirrup and figure of eight. On the word "Eight."—The stirrup is "sprung" on to the splint above the ankle, its foot toward the stretcher. A bandage is then applied

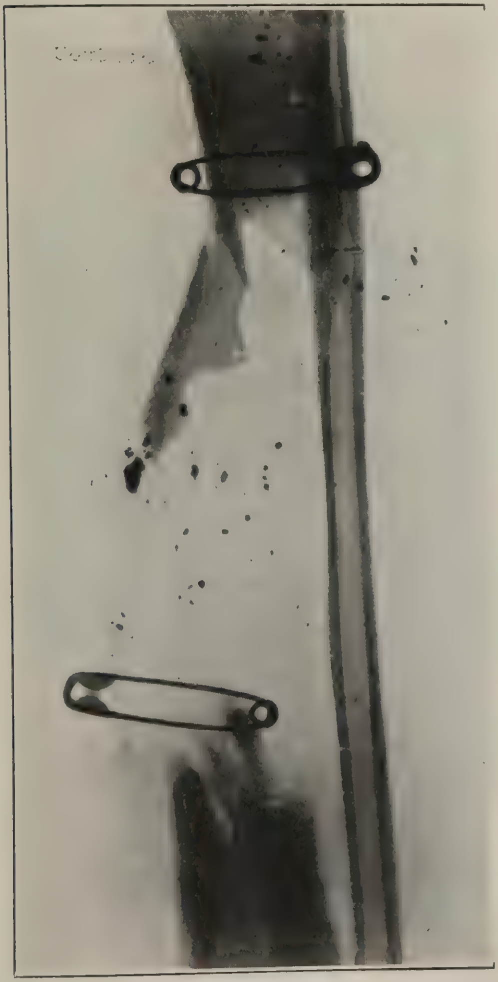

FIG. 67.—Extensive destruction of shaft of tibia caused by shell fragment. Metallic dust is shown in the surrounding soft parts. X-ray taken subsequent to débridement

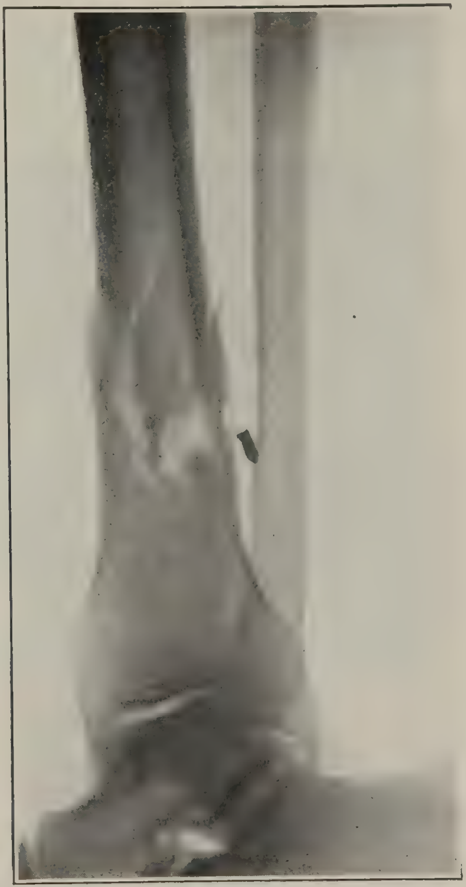

FIG. 68.—Perforating wound of lower end of diaphysis of tibia. Though there is comminution of the bone the fragments are not widely separated. Foreign body lodged between tibia and fibula

to form an additional sling, and by a figure-of-eight turn prevents lateral movement of the foot.

IX. Spanish windlass. On the word "Nine."—The extension bands are tightened, and a small piece of wood or a nail is introduced to increase the tension by twisting up as required.

X. Pad in ring. On the word "Ten."—A pad is placed inside the ring on the outer side of the thigh to act as a wedge and prevent undue movement.

XI. Suspension bar. On the word "Eleven."—The suspension bar is fitted to the stretcher with the "grip" away from the rackets. The splint is slung up three fingers' breadth from the horizontal part of the suspension bar. To damp down the side movements, lateral tapes are tied to the uprights. For the journey in the motor ambulance car an additional band may be passed from the splint round one handle of the stretcher.

XII. Hot-water bottles and blankets. On the word "Twelve."—Hot-water bottles are applied. The third blanket is folded into two lengthwise and laid over the patient. The hanging folds of the first and second blankets are brought up over this so that the patient is evacuated with four folds of blanket on top as well as underneath.

It was surprising how efficient the men became in the application of this splint, even if they had had but little training. As a matter of fact, the above technique could not be so methodically carried out in a shell hole, but the splint could be put on under almost any condition so that the wounded man could be moved back fairly comfortably to where proper adjustment could

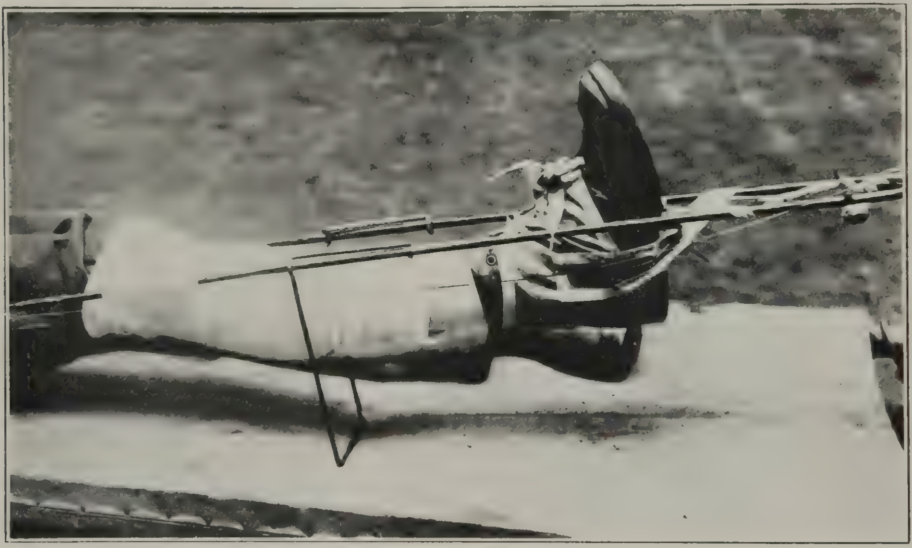

FIG. 69.—Cloth gaiter, applied over shoe for extension

be made. The comfort of the patient was in direct ratio to the efficiency of the application of the splint, and the task of the litter bearers was much easier if their patient was uncomplaining.

Where there was an extensive wound of the thigh and hip the long Liston splint was applied in some cases and, while it was far from satisfactory, it was of value. For the knee-joint injuries and the upper leg fractures the Thomas splint was used almost exclusively, as it was found to be more comfortable than the Cabot splint. The latter, however, was used to some extent in this group when there occurred a shortage of Thomas splints.

As a rule, men with fractures of the lower extremity were in greater shock on arrival at the ambulance dressing station and required more care than did those with fractures of the upper extremity.

The Cabot posterior wire splint was applied to fractures of the lower extremity occurring so far down the leg as to prevent applying traction to the foot without danger. The important points to be remembered in its use were

the necessity for pressure pads behind the ankle and behind the knee and the additional use of lateral wire-ladder or board splints to more securely fix the limb.

OPERATIVE TREATMENT IN HOSPITALS AT THE FRONT

As a rule every gunshot fracture was operated upon, with the exception of the through-and-through machine-gun bullet wounds in which there was little comminution of the bone. The operation (débridement) necessarily included attention to the soft parts as well as to the bone. Since débridement of the soft parts has been given full consideration in Chapter XI of the volume on general surgery no further mention of it will be made here.

When cases of gunshot fracture reached those advance hospitals in which it was possible to do aseptic surgery, they were inspected as to their general condition and as to the condition of their wounds. Patients in bad general condition were sent to resuscitation wards until their condition permitted proper surgical treatment. An almost invariable prelude to any operative intervention was an X-ray examination.

The extent of operative treatment of the fractured bone was contingent upon the presence or absence of infection. Penetration of the diaphysis was usually considered as giving rise to infection of the medullary canal, thus necessitating laying open and exploring it. Detached bony fragments were invariably removed; such fragments are foreign bodies, and if left, necrose in the presence of infection, thus leading to troublesome subsequent bone fistulæ. In the event it was expedient to remove fragments that were still attached to the periosteum, to effect the necessary exploration and cleansing of the medullary canal, these fragments were so removed as to leave the periosteum intact to insure future osteogenesis.

It was the almost invariable rule not to close, by primary suture, any compound fracture wounds in the hospitals at the front, in view of the fact that patients so injured necessarily had to be evacuated at the earliest possible time and therefore could not remain under the observation of the surgeons originally treating them. Usually, Dakin tubes were inserted and dressings applied, whereupon the patients were turned over to splint teams whose duty it was to make proper alignment of the fractures and to apply permanently the necessary splints.

Since sepsis was met more commonly in compound fracture cases in the base hospitals, the treatment of this complication is given subsequent consideration in connection with the later treatment of compound fractures.

FIXATION TREATMENT IN MOBILE AND EVACUATION HOSPITALS

The splints for the treatment of fractures in mobile and evacuation hospitals, while necessarily embodying principles which would effect fixation and traction, according to the necessity of the case, nevertheless, because of the transitory stay of patients in these hospitals, inevitably had to conform to the restrictions imposed by the necessity of transporting the patients farther to the rear; that is to say, the splints must be few in number; they must be speedily and rapidly applicable so as to make immediate transportation possible. To this end

the following instructions were issued to surgeons of mobile and evacuation hospitals.[1]

Familiarize yourself with the exact number of each splint and splint accessory now in the hospital necessary to carry on the work. Check up with the following list and have the commanding officer requisition the splints not on hand.

List of Splints, Splint Accessories and Dressings for an Evacuation Hospital 1,000 Beds

Splints:	
Open-bite intermaxillary splint	20
Snowshoe litters	10
Hinged modification of Thomas arm splint	100
Thomas traction leg splint	125
Hinged half-ring modification of Thomas leg splint	100
Cabot posterior wire splint	200
Wire-ladder splint	400
Long interrupted Liston splint	15
Splint wood, 3 feet	200
Splint wood, 4 feet	200
Galvanized net cone gauze	20
Splint rests, wire	300
Stretcher bars	50
Foot supports, wire	300
Wrist and hand splint	150
Splint accessories:	
Safety pins, 1½-inch, gross	10
Safety pins, 2¼-inch, gross	6
Straps and buckles, 1½-inch by 5 feet	300
Straps and buckles, 1½-inch by 6 feet	300
Slings	1, 000
Canvas hammocks	10
Plaster of Paris, cans	5
Jackinette, meters	10
Adhesive plaster, Z. O	20
Sheet wadding, 5-inch by 5 yards, rolls	500
Stockinette, sizes 1, 2, and 3, of each	1
Crinoline, bolts	10
Felt, yards	500
Supporting slings, 8 by 21 inches	500
Supporting slings, 5½ by 16 inches	800
Supporting slings, 25 by 7 inches	500
Rubber cloth supporting slings, 8 by 24 inches	400
Rubber cloth supporting slings, 5½ by 16 inches	400
Glue, resin, and turpentine, liters	2
Glue, Sinclair's, cakes	2
Dressings:	
Gauze rolls	1, 000
Sponges or wipes, 2 by 2¼ inches, packages	1, 000
Sponges or wipes, 4 by 4½ inches, packages	1, 000
Absorbent pads	5, 000
Paper-back bed pads, size 1, 10 by 18 inches	3, 000
Paper-back bed pads, size 2, 18 by 25 inches	3, 000
Bandages, 4 inches by 5 yards, muslin	500
Bandages, 5 inches by 5 yards, muslin	500
Bandages, 6 inches by 5 yards, muslin	500
Gauze bandage, 1 size	3, 000
Gauze, plain, yards	10, 000
Scultetus bandages	100
Jacket, pneumonia	10
Absorbent cotton rolls, pounds	200

2. Keep this supply always on hand, by requisition on advance medical supply depot or on emergency depot of your area.

3. Establish special splint depot for your hospital either in tent or room, as seems best, where splints are always under your control and ready for use.

4. Keep operating room adequately supplied with splints and splint accessories, so that they may always be ready for immediate usé.

5. As soon as operation has been finished and dressings applied have your splint team immediately apply proper splint. You will be held responsible for the proper splint of each case.

6. Supervise the splinting of each case in the wards and see that the apparatus is in proper order at all times during the patients' stay in the hospital.

7. At time of evacuation see that all apparatus is properly adjusted so that it will effectually stand transportation.

8. Establish an exchange bureau at receiving ward where ambulance driver may receive a splint for the one left on patient. All ambulance drivers are required to obtain splints, stretchers, and blankets to replace those they have left with the wounded.

Satisfactory fixation can not be obtained unless the splinting material used extends well above and well below the lesion. The fixation splints used in these hospitals were the snowshoe litter, the long Liston splint, Cabot posterior wire, and such fixation material as board splints, wrist and hand splint, and wire-ladder splinting. In certain exceptional instances plaster-of-Paris casts and shells.

Wherever possible traction splints were to be used. For example, in fractures of all long bones and in war injuries to the knee and elbow joint.

The traction splints recommended for use in these hospitals were: The hinged traction arm splint; Thomas traction thigh and leg splint; hinged half-ring thigh and leg splint.

Traction was obtained by means of adhesive material fastened to the skin. Zinc oxide adhesive was provided for this purpose and was used preferably in fractures of the upper extremity. The adhesive bands were so applied as to avoid constriction of the limb. The strips were tied to the end of the splint and further traction made by the use of a small piece of wood or nail in the manner of a Spanish windlass.

Many surgeons preferred to use a glue applied to the leg with a brush, the last stroke of the brush being upwards in the direction opposite to the growth of the hair. Extension strips of unbleached muslin were used for this purpose.

Two types of glue were provided—Sinclair's, and resin and turpentine, permitting traction to be made within five minutes after the application. Sinclair's glue consists of best cabinetmaker's glue, 50 parts; water, 50 parts; glycerine, 2 parts; calcium chloride. 2 parts; thymol, 1 part. This glue should be heated in a water bath at a temperature of about 100° F. before using. The addition of sufficient bicarbonate of soda will slightly alkalinize the reaction. The resin and turpentine glue consists of resin, 50 parts; alcohol, 50 parts; benzine (pure), 50 parts; Venice turpentine, 5 parts.

Powder the resin, then add half the alcohol, then the Venice turpentine and benzine, washing the measure into the bottle with the remaining alcohol. This glue may be removed with alcohol or ether. The bottle containing the glue should be kept tightly stoppered else the proportions of the constituents may change, and the glue become irritating to the skin. This glue does not require heating before use, and should not be applied too thickly.

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TREATMENT IN BASE HOSPITALS

Because it frequently was necessary to move patients from base hospitals farther to the rear, or even to the United States, their transient status had to be kept constantly in mind, in so far as fracture treatment was concerned. Therefore, the principles used in the treatment of fractures for transportation always had to be borne in mind and the necessary apparatus maintained to carry them out.

Fig. 70.—Fracture ward, Base Hospital No. 41, St. Denis, Paris

In addition, however, more permanent apparatus was provided for fracture cases which remained in the hospital for the greater part of their treatment and convalescence. This apparatus included the following articles:[1]

List of Splints, Splint Accessories, and Dressings for a Base Hospital of 1,000 Beds

Splints:

Open-bite intermaxillary splint	25
Hand and wrist splint	100
Thomas arm splint	100
Hinged modification of Thomas arm splint	25
Jones humerus traction arm splint (right)	25
Jones humerus traction arm splint (left)	25
Thomas traction leg splint	150
Anterior thigh and leg splint, Hodgen type (right)	50
Anterior thigh and leg splint, Hodgen type (left)	50
Wire-ladder splint	100
Cabot posterior wire splint	50

Splints—Continued.

Jones cock-up crab splint	50
Splint wood, 3 feet	100
Splint wood, 4 feet	100
Maddox frame tubing, 3½-foot lengths	100
Maddox frame tubing, 8-foot lengths	100
Maddox clamps	300
Special clamps	300
Balkan frame, complete with poles	150
Screws for Balkan frames	400
Strap-iron hooks for Balkan frames	200
Small iron pulleys	200
Paper clips	500
Sash cord, size ⅛-inch, feet	200
Sash cord, size $\frac{3}{16}$-inch, feet	200
Galvanized net cone gauze	10
Weight bag container	300
Buckshot bags, filled 250 grams	200
Buckshot bags, filled 500 grams	200
Tool outfit	1
Nut wrench for Maddox frame	2
Ice tongs	5
Splint rest, wire	100
Foot support, wire	100

Splint accessories:

Safety pins, 1½-inch, gross	10
Safety pins, 2¼-inch, gross	6
Straps and buckles, 1½ inches by 6 feet	100
Straps and buckles, 1½ inches by 3 feet	100
Slings	250
Elbow traction bands	50
Canvas hammocks	10
Plaster of Paris, cans	20
Bandages for plaster	500
Jackinette, meters	10
Sphagnum moss pads, 7 by 11 inches	400
Sphagnum moss pads, 14 by 20 inches	400
Heel rings	20
Canvas swathes	36
Adhesive plaster, zinc oxide	20
Sheet wadding, 5 inches by 5 yards, rolls	500
Stockinette, size 1, 2, and 3, of each	2
Crinoline, bolts	10
Felt, yards	10
Supporting slings, 8 by 21 inches	300
Supporting slings, 5½ by 16 inches	500
Supporting slings, 23 by 6 inches	200
Rubber cloth supporting slings, 5½ by 16 inches	200
Rubber cloth supporting slings, 8 by 24 inches	200
Glue, resin and turpentine, liters	3
Glue, Sinclair's, cakes	3

Dressings:

Gauze rolls	300
Sponges or wipes, 6 by 2¼ inches, packages	500
Sponges or wipes, 4 by 4½ inches, packages	500
Paper-back bed pads, size 1, 10 by 18 inches	2, 000

Dressings—Continued.

Paper-back bed pads, size 2, 18 by 23 inches	2, 000
Bandages, 4 inches by 5 yards	1, 000
Bandages, 5 inches by 5 yards	1, 000
Bandages, 6 inches by 5 yards	1, 000
Gauze bandages, 1 size	1, 000

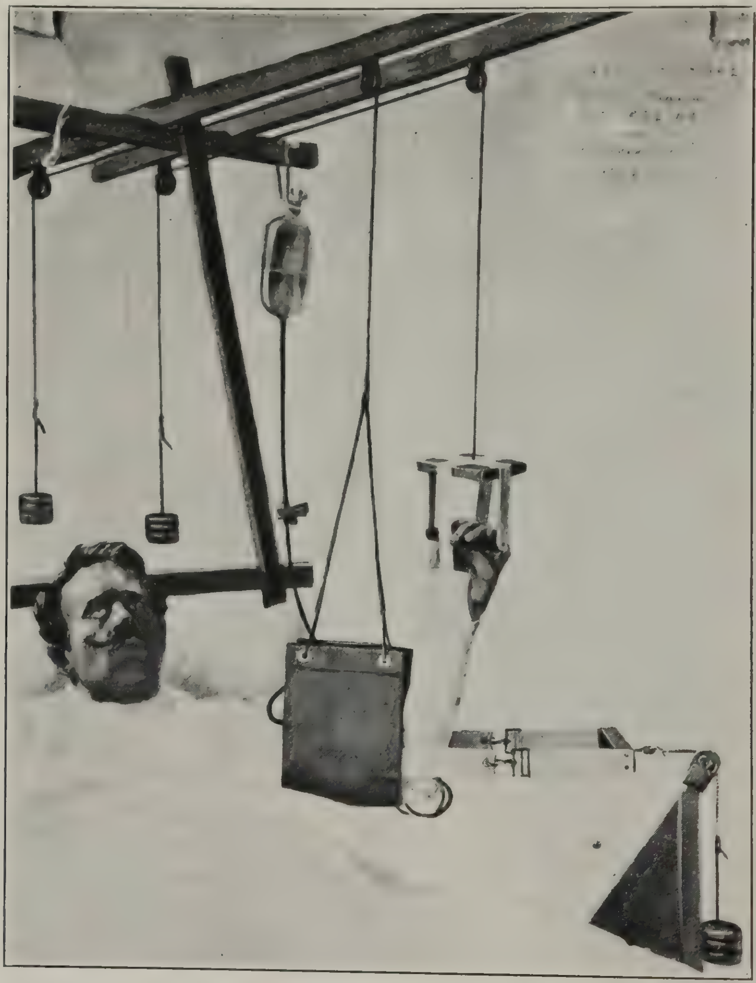

Fig. 71.—Treatment of fractured humerus

UPPER EXTREMITY

To successfully transport a patient with fractured humerus back to a base hospital, the hinged traction arm splint was generally preferred because it allowed the arm to come down to the side of the body, thus facilitating the transfer; however, many patients reached the base hospitals in straight arm splints and in Jones traction arm splints. Efforts were made to maintain the length of the humerus even though a section of the bone had been removed, as it was found that new bone often formed to bridge such a gap, especially when any periosteum remained.

FIG. 72.—Compound, comminuted fracture involving shoulder joint. Arm abducted; hand semisupinated

FIG. 73.—Compound, comminuted fracture involving shoulder joint. Cast in position of abduction; hand semi-supinated. Note windows cut for dressing and pelvic support

When a man with a fractured humerus arrived at the base hospital, the apposition of the fragments was considered. Up to this time, most of the attention had been centered on the control of sepsis, extension and fixation had been used to approximate the fragments as nearly as possible and to make the transportation of the patient as comfortable as could be. The case was X-rayed as soon as possible; better drainage was instituted if necessary, and attention was given to approximation of the fragments. In fractures of the upper third the arm was abducted, and if the patient had come back in a hinged Thomas splint, this usually was removed and a Thomas humerus traction splint applied. It was noted that often the arm was left extended at the elbow for too long a time, resulting in difficulty in getting flexion at the joint after the fracture had healed. It was also noted that too much abduction was maintained in some cases, but this produced no disability. In cases where the head of the humerus and the shoulder joint were involved abduction of about 45°, with traction, was maintained with the forearm in supination, as this is the best position in ankylosis. When the arm was fractured in the middle third, it was extended with traction and the forearm placed in about two-thirds supination. In the lower third, flexion of the elbow to a right angle with the forearm in complete supination, with traction on the forearm, was the most favorable position in which to maintain apposition. The Jones humerus traction splint was most adaptable for this type. The arm was suspended by means of the Balkan frame in practically all of the cases. This suspension added to the patients' comfort and facilitated irrigating and dressing the wounds. Continuous irrigation by the Carrel-Dakin method was used in most of the badly infected cases. The results were entirely satisfactory where it was possible to maintain the proper technique.

The management of the sepsis often required additional drainage and the removal of sequestra. In other words, the osteomyelitis had to be treated. In some cases, too much operating was done with the result that the infection was spread into new areas and septicemia developed. It was found that the better policy was to allow the condition to become subacute and to wait until the sequestra had become loose before attempting their removal.

After union had occurred in the cases of fracture of the upper third of the humerus, it was the custom to get the patients up and out of bed. This necessitated putting the fracture up in some form of ambulatory abduction splint. Inasmuch as very few airplane splints were available, it was necessary for orthopedic surgeons to devise and manufacture their splints, thus resulting in the use of about every kind and type that provided flexion at the elbow and extension of the abducted upper arm.

Most of the hospital centers in the American Expeditionary Forces developed some kind of an orthopedic shop for making the needed accessories in the splint line. Many cases required special splints that were not available on requisition and these also were made in the special shops.

Forearm, Wrist, and Hand

Compound fractures of the forearm presented great difficulty in their treatment. In fracture of both bones, on account of the usual comminution and projection of bone splinters into the soft tissues, cross union or callus

interference frequently occurred; moreover, adequate drainage was difficult to maintain, owing to the numerous muscles and tendons. Extensive sloughing of tendons caused lamentable loss of function in several cases. It was important to maintain traction in fractures of the radius and ulna even when only one bone was broken, especially was this true in fractures of the lower portion of the radius as mesial deviation of the hand with marked loss of function occurred if the radius shortened. Usually the Jones humerus traction splint was applied in these cases, the traction being maintained by tying the adhesive strips to the end of the splint. These cases were evacuated early and after they reached the base hospital further extension was made by applying traction to the splint by means of a weight and pulley after the splint was suspended.

FIG. 74.—Method of treatment of fracture of both bones of forearm

They were treated as bed cases until after the infection had been controlled. In many instances, the hinged arm splint or the Thomas traction arm splint, when bent to a right angle at the elbow was well adapted to these cases. The hand was completely supinated in a large percentage of the cases treated. When partial union had taken place it was usually not necessary to change the type of splint in order to allow the patients to become ambulatory.

The chief difficulty encountered was maintaining traction; if the wound extended to the lower third of the forearm there was very little room to apply adhesive tape; owing to circulatory conditions it was not possible to apply a bandage tightly to the wrist. To secure needed traction, Sinclair's method of gluing a cotton glove to the hand was very satisfactory when used; also it was possible to secure considerable extension by applying strips of adhesive

FIG. 75.—Compound comminuted fracture, carpal and metacarpal bones, showing banjo splint with traction of fingers and molded palm. Plaster splint fitted to palm of hand with moderate dorsal flexion of wrist

tape to the fingers and tying the ends to the splint, due care being taken, just as with the glove, to equalize the pull on the fingers. Marked swelling of the soft parts was frequent, but very few cases of ischemic paralysis resulted, probably due to the fact that the wounds prevented destructive pressure on the muscle tissue. Frequent drainage operations were necessary but fewer operations for sequestra were required, as compared with other bones.

Fractures involving the bones of the wrist and hand frequently were kept for too long a time in straight splints and often when the Jones "cock-up" splint was used, the fingers became stiff in extension. The reason for this is obvious. These injuries were not serious as to life and the surgeon's attention was centered on the important cases. This condition, however, required much effort in the readjustment, such as dorsi-flexing the wrist and mobilizing the wrist and fingers.

Fig. 76.—Application of finger splint, showing extension applied

LOWER EXTREMITY

Gunshot wounds of the femur were among the most fatal injuries that were dealt with in the war. A simple fracture of the femur occurring in civil practice is even more serious than it is usually considered, and often is difficult to bring to a successful result. If one stops to consider the problem of the management, in all its many phases, of a compound fracture of the femur as presented by modern warfare, it is remarkable that the mortality, while exceedingly high, was not higher. The most practical lesson taught by the World War in the management of fractures is to be gained by a study of the management of compound fracture of femurs. The British have estimated that the mortality from femur fractures including complicated cases was between 40 and 50 per cent in 1914–15 and in 1918 between 20 and 30 per cent, including all cases, and that in the uncomplicated fractures, treated by the most modern methods the mortality was not more than 15 per cent.[2] This change was brought about by improvement in their methods of first aid, operating, splinting, nursing, and after care, of which we were able to take full advantage, for, of the 3,367 men who had fractured femurs in the World War, 917 died, thus giving a mortality of 27.23 per cent.[3]

When the fractured femur cases were received at a base hospital, it was always a problem to get them properly adjusted, the cases required immediate change of dressings and such adjustments as would permit them to rest, as they were usually worn out from the journey and had the same dressings on that they started out with. The following extract from the report of the orthopedic consultant at Mesves Hospital Center to the chief orthopedic consultant, A. E. F., is quoted as an example of how the work was planned there:[4]

The admission of fracture and joint cases was so great during the month of October that it became necessary to establish 16 fracture wards in the various hospitals. Owing to the fact that it was necessary to change the dressings on all these cases on admission, it was

FIG. 77.—Balkan frame, showing suspension apparatus. Thomas splint

impossible for the ward surgeon to adjust splints, erect Balkan frames, and apply extensions. Splint teams were organized, consisting of 1 medical officer, 1 sergeant, and 1 private. As soon as the ward began receiving patients, this team was sent in to erect frames and suspend the cases. Usually this could be done for all the urgent cases in a day. The ward surgeons could easily change the dressings on 52 cases in a half day if all were properly suspended. This allowed him the remainder of the day for the adjustment of apparatus. The industrious medical officer was able to make all of his patients comfortable and secure good alignment under this régime. It was also possible to control sepsis and our records show that the mortality of fractured femurs among our later cases was very low indeed. The rate in our first cases was rather high for the reason that the cases became thoroughly septic before we could arrange to handle them properly. The mortality among all cases was about 17 per cent.

Practically all of the cases of fractured femurs came back from the triage and evacuation hospitals in Thomas splints. After they had been received and examined at the base hospitals, it was often found that the Hodgen splint was better adapted for cases with wounds high up on the thigh or in the groin and consequently the Thomas splint was removed and the Hodgen splint applied.

Very few long Liston splints were used and it was quite noticeable in many of the base hospitals that as the work progressed there were fewer and fewer attempts made to devise any new form of splinting and a greater tendency to use the Thomas splint exclusively. In cases where a Hodgen splint was indicated it was not uncommon to find that the medical officer had bent a Thomas half-ring splint at the knee and applied it upside down with the one-half ring anterior instead of posterior. No elaborate plans were used in connection with the splinting other than suspension by means of the Balkan frame. A few cases, however, with buttock and back wounds, were very difficult to manage. In these cases an effort was made to have the patient persist in pulling himself up off the bed by grasping with his hands a bar that was suspended from the top of the Balkan frame, and if he was able to do this, the changing of the dressings on the wounds was much easier for him.

The position of the leg in fractured femurs varied of course with the location of the fracture. In the upper third, traction, nearly complete abduction and external rotation of considerable degree was insisted upon with the leg in suspension. Until these cases reached a base hospital no special effort had been made to secure apposition of the fragments, the care having been divided between prevention of sepsis and immobilization for the purpose of comfort during transportation. During the first few weeks after our casualties began coming in there was a tendency among some of the surgeons at the hospital to continue to ignore position and to wait for an improvement in the sepsis before attempting improvement in the alignment. It was found out rather early that securing and maintaining the best possible apposition was the best possible treatment for the sepsis. This was shown to be true in many instances and the probable explanation is that when full length of the leg is secured, with only moderate or no displacement, the sheaths of the muscles are taut and the muscle bundles are in normal relation so that there is less opportunity for pus to burrow along the muscle and thus infect new areas.

The observation was repeatedly made that the infection extended along the fascial planes in the limb. Advantage of this fact was taken by changing the position of elevation in the badly infected cases, so that the pus would not gravitate down these planes.

In fractures of the middle third of the femur, great difficulty was experienced in getting the ward surgeon to maintain sufficient outward rotation. The position of 30 to 35 degrees of outward rotation is necessary to secure apposition on account of the fact that the external rotators of the thigh produce nearly complete outward rotation of the upper fragments. It was also necessary repeatedly to insist upon the normal anterior curve of the femur being exaggerated in order to prevent posterior bowing which gives raise to disability. Slight flexion of the knee and thigh was also insisted upon. Many

FIG. 78.—Fracture of femur, showing double extension. Inverted Hodgen splint

devices were used to prevent lateral bowing which in some cases was difficult to overcome in fractures above the lower third.

Fractures of the lower third of the femur were very trying, and we did not really succeed well with them until after the beginning of the use of skeletal traction by Pearson's modification of the Besley "ice tongs." It is practically impossible to secure apposition in this type of fracture without 70 or more degrees of flexion at the knee, and it is then very difficult to apply any kind of skin traction.[2]

In the comparatively few cases in which the "ice tongs" were used, the results were most satisfactory. In the early spring of 1919, after some of our medical officers who had been detailed for service with the British were returned to the American Expeditionary Forces, a number of compound fractures of the lower third of the femur were treated with tongs. In this series no bad effects were noted, and when the tongs were properly applied the patients were entirely comfortable, it being necessary only occasionally to remove and reapply them.

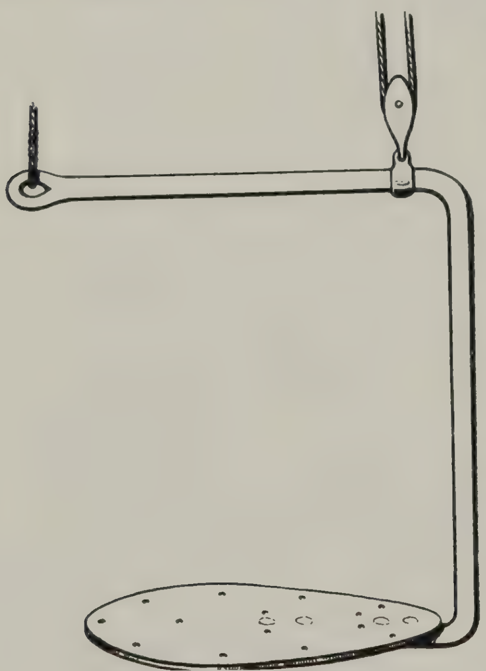

FIG. 79.—Pelvic lifter

The treatment of compound fracture of the head and neck of the femur, on the whole, was rather discouraging. Many of these cases were complicated by injuries to pelvic viscera and pelvic bones, and as a result offered very little from the treatment standpoint. They were difficult to care for and often it was not possible to make them entirely comfortable. Usually they were treated in abduction with the Thomas splint, or some modification of it for support. A plaster of Paris spica was always preferred but, on account of the wounds and suppuration, it could rarely be used. The head and neck of the femur were observed to have very little resistance to infection. A through-and-through bullet wound of the head or neck, with no comminution or displacement, and with but little or no apparent infection, would often result in complete destruction of these parts. Abscesses would form in the pelvis in this group of cases, and because they were detected with difficulty amputation was frequently necessary. It was found that these abscesses could be drained successfully by following the ilium. Many of these cases that were very septic would finally make good recovery, with healing of all the sinuses.

Very few secondary closures were attempted in compound fractures of any kind, either after the primary operation or after the sequestrotomy. However, experience indicated that under proper conditions a technique could be

perfected that would permit secondary closure in a large percentage of compound fractures.

A report of the fracture work in Base Hospital No. 27, Angers, France, which was made to the chief consultant in orthopedic surgery at the time the hospital practically finished its work is quoted in full:[5]

On July 16, 1918, following the return of the orthopedic surgeon to the hospital, the orthopedic department was made separate from the surgical, and so remained for a period of four months, during which time most of the casualties from the front were received. The department expanded rapidly in size, due to the influx of wounded with compound fractures,

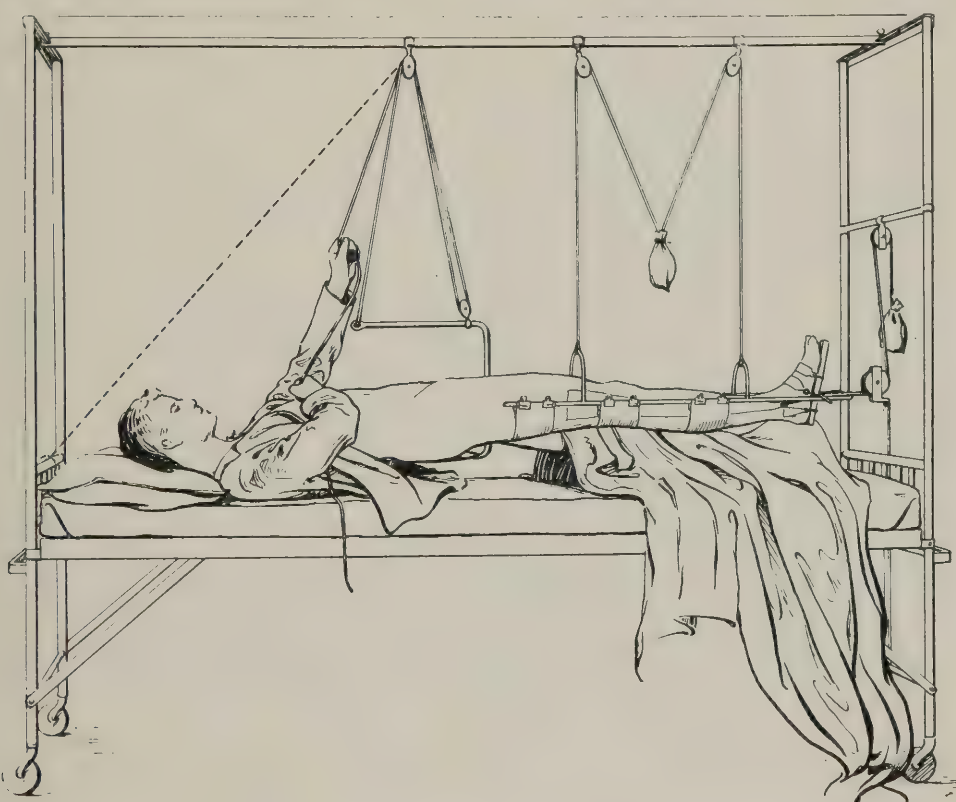

FIG. 80.—Method of using pelvic lifter

necessitating a corresponding enlargement of bed space on the third floor of the main building, where the fracture cases had previously been quartered as a part of the surgical service. The first large convoy of fracture cases arrived July 21, 1918, and as these were preoperative and from three to five days from date of wounding, their condition was unfavorable and necessitated extensive and radical operations. Subsequently, many large convoys were received, but none in which the majority of cases had not already been operated. The total number of occupied fracture beds rose from 80 on July 15, 1918, to about 250 by the middle of August and over 300 in September. Likewise, the routine orthopedic cases, now being retained for treatment, averaged about 100 in this hospital, and considerably more in the hospital annex. Aside from these two general types of cases, there was also handled by the department, mostly through individual consultations by the chief orthopedist, a large proportion of surgical wounded presenting conditions threatening deformity, or functional

derangement, many of which cases were later transferred to the orthopedic service for treatment. The gravity of the cases with fractures and joint wounds, and the demands upon the personnel for their care, soon centralized the department around these cases, and necessitated a change in the fracture wards to a location in the hospital offering more convenience and elasticity for expansion. The fracture service was therefore moved about the middle of August from the third floor of the main building to four connected wards in the principal group of ward barracks, from which as a nucleus the increasing demand for bed space could be met. From the first, attention was put on the simplification and standardization of methods and technique in handling these cases, to insure rapidity in completely caring for each case on admission of a large convoy and for uniformity of treatment throughout. Definite rules and routine were worked out for the management of cases on admission and discharge and for their mechanical and surgical treatment. With the use of standard splints and apparatus, the suspension technique of Blake was modified principally with a view to less complexity of weights and pulleys, all weights being carried to the head of the bed and the trolley suspension abolished. For the arm a right-angled traction bar, attached to the Balkan frame, was designed to take the place of the bed board and found satisfactory. Extrinsic traction, by weight and pulley, was employed in most cases, though the intrinsic method in the Thomas splint, with the splint attached to the running weight, was used in some. This standardized apparatus could be put up rapidly by trained orderlies, allowing the medical personnel freedom to meet the surgical conditions presented by the new cases, the correction of the mechanics to the individual condition following the bedside X-ray examination, after the patient had been suspended.

During the first few weeks of this four-months period, great effort was made to elaborate the mechanics in special cases, where unusual bone deformities presented as in fractures of the femur, near hip and knee, and in fractures of the humerus. Much of this was omitted following the adoption of more routine apparatus, being also coincident with the receipt of orders hastening the evacuation of all cases which could not regain "A" class in a reasonably short period. All efforts of the department, therefore, were directed toward preparing cases for early evacuation, and the splinting was correspondingly modified to better meet the demands of transport. The Thomas leg splint almost entirely superseded the Hodgen, while flexion of the knee and flexion and abduction of the hip were limited to 30 degrees. An arbitrary time limit of two months was put on all cases in the orthopedic department, as the maximum allowed patients to regain combat fitness so that practically all fractures and joint wounds were considered cases for evacuation from the day of their admission, and the principal attention of the personnel was directed toward the surgical cleansing of the wound (Carrel-Dakin method being employed throughout). It was, therefore, natural that the operative treatment should be largely confined to combating infection, about 100 operations for the establishment of drainage, removal of foreign bodies and devitalized tissue being performed in this four-months period, as compared with 15 secondary sutures. Despite the fact that during the first month many fracture cases were kept for complete consolidation and the return of function, the average length of stay in the hospital for all fractures was six weeks.

The following figures give the number of fractures of each region with the average length of stay in the hospital for the four months, July 15 to November 15, 1918:

Region	Number	Average stay
		Days
Spine	13	28
Hip and pelvis	17	53
Femur	82	49
Knee-joint and patella	82	48
Tibia and fibula	180	45
Ankle and foot	122	42
Clavicle	23	30
Shoulder	66	38
Humerus	99	46
Elbow	40	31
Radius and ulna	136	42
Wrist and hand	124	42

Tibia and Fibula

It was stated above that the Thomas splint, or its half-ring modification, was used for the first-aid splinting of fractures of the upper two-thirds of the tibia and fibula and the Cabot splint for fractures of the lower third, ankle, and foot. This rule also obtained after the primary operation had been performed at the advance operating station. Extension was made by adhesive strips for the upper leg fractures and very little difficulty was encountered in maintaining sufficient traction in this group of cases. However, in the lower third fractures it was extremely difficult to secure sufficient traction and many methods were used. Strapping or gluing a board to the sole of the foot after the method suggested by Sinclair was probably the most satisfactory, as it was found the rotation of the foot could better be controlled by this plan. In

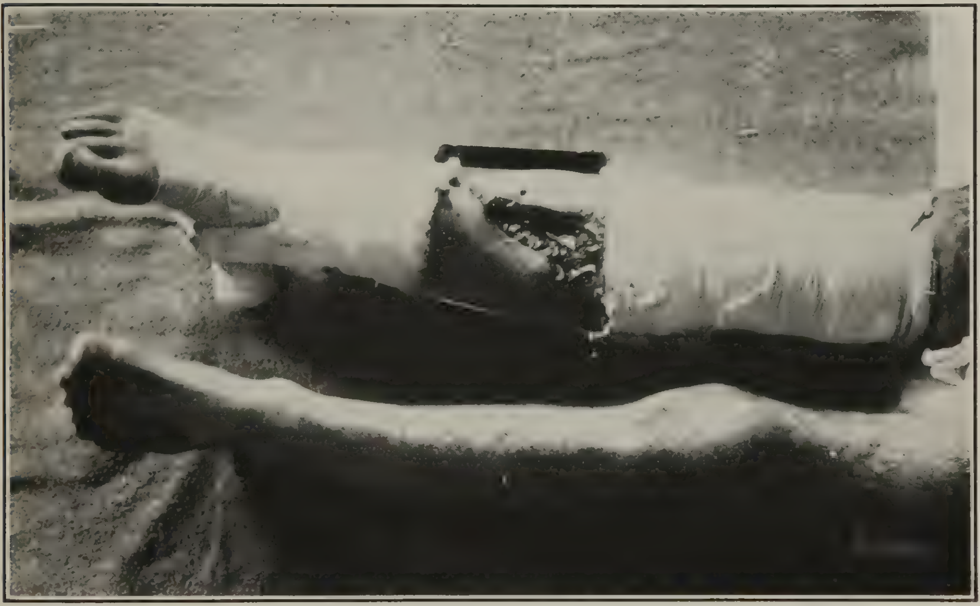

Fig. 81.—Bridge transportation splint for fracture of tibia

all fractures of the lower extremity an attempt was made to keep the foot at right angles to the leg by applying a strip of adhesive plaster to the sole of the foot and attaching it to the overhead bars of the Balkan frame. Applying a cast to the foot and then making traction over the cast was not at all satisfactory, as it was found that pressure necrosis occurred on the dorsum of the foot in a large number of cases. The use of the ice tongs applied to the os calcis was satisfactory; no bad effects were noted. On the other hand, where a Steinman pin was passed through the os calcis, troublesome osteomyelitis often developed.

Compound fractures of the upper third of the tibia extending into the knee-joint were always serious, and many amputations were done for this type of fracture. In many cases a prolonged attempt to save the leg resulted in loss of the patient.

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In fractures of the middle third, posterior sagging of the tibia too often occurred. This deformity leads to permanent disability of considerable degree, and is of greater inconvenience to the patient than shortening or outward

FIG. 82.—Delbet plaster splint for fracture of tibia

bowing. Internal bowing is also disabling on account of the strain produced on the ankle and foot. This deformity, however, occurred more frequently in

FIG. 83.—Plaster splint for fracture of tibia, permitting mobilization of ankle

the lower third fractures of the tibia. Nonunion was of greater frequency in the tibia than in any other bone.

Compound fractures of the fibula alone seldom occurred and offered no particular problem when encountered. Usually the fracture of both bones

was at the same level and the treatment of the fibula was incidental to the tibia. Nonunion of the fibula in the upper lower third and middle third produced but little if any disability and seldom if ever occurred in any other region of the bone.

FIG. 84.—Bridge plaster splint for fracture of tarsal bones

Compound fractures of the tibia and fibula required protection from weight bearing for a long period of time, and this fact no doubt contributed to nonunion. The walking caliper splint was not as effective in protecting these bones as it was in the femur, and no entirely satisfactory plan was worked out, probably the Delbet plaster splint being the best method tried.

Tarsal Bones

Fractures of the tarsal bones were often extensive. The Cabot splint was admirably adapted for the treatment of these cases. The infection was difficult to control owing to the extensive swelling that accompanied these injuries, with resulting interference with the blood supply. A diseased tarsal bone would seldom regenerate and, as a rule, it would become a sequestrum and be extruded as a whole. Fortunately, the ankle joint rarely became completely ankylosed and where some motion remained the stiffness of the foot was partially accommodated for.

In tarsal bone fractures, as well as in carpal bone fractures, the Carrel-Dakin method of irrigation was not as satisfactory as it was in fractures of the long bones, due to the fact that free drainage of the infected area was not so readily obtained. Late amputation was more frequent in the tarsal fractures than in any other group of cases. This condition resulted from the fact that so much destruction occurred before the infection was controlled that the function of the foot was interfered with to such an extent that an amputation was to be preferred. In the hand injuries, the reverse was true, as almost any portion of the hand and fingers that could be saved was of more value than any artificial hand that has ever been devised.

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(3) Annual Report of the Surgeon General, U. S. Army, 1920, 277.
4) History of the Mesves Hospital Center, Part II. On file, Historical Division, S. G. O.
5) History of Base Hospital No. 27 (Hospital Center, Angers, France). On file, Historical Division, S. G. O.

CHAPTER IV

ORTHOPEDIC SURGERY IN EMBARKATION HOSPITALS, A. E. F.[a]

The experience of those of our orthopedic surgeons who served first in Great Britain and then in France showed that the problem of dealing with the war wounded from the orthopedic standpoint was somewhat as follows: In general these cases were fractures, both simple and compound; joint injuries; peripheral nerve and spinal cord injuries; soft-part injuries, with tendency toward contracture deformity; static disabilities of the trunk and extremities (spine, sacroiliac, feet, etc.); amputations; and the making and application of all splints, braces, and prosthetic devices.

Wounded soldiers returning from the front (either directly or through evacuation hospitals) early began to give evidence of the need of orthopedic treatment. Even the early convoys to the United States showed that more careful splinting and preparation of the patients otherwise than as had been done would be necessary if the American wounded were to be properly transported from France to the United States. Accordingly, the organization of the orthopedic service in base hospitals was thoroughly arranged during the summer of 1918, with the following objects in mind: (1) To treat surgically, splint, and otherwise deal promptly with those who could soon be returned to duty as class A or B. (2) To prepare as many of the class D patients as possible for early, safe, and comfortable transportation to the United States. (3) To arrange suitable hospital facilities and care for serious cases that must be treated and their reconstruction begun in France.

Most of the American wounded who belonged in the first group were returned to duty without comimg to base hospitals at all. A considerable number, however, with strains, dislocations, fractures, sacroiliac injuries, weak foot, flat foot, and even minor amputations, came to base hospitals and were discharged to duty after a few weeks' treatment.

Patients in the second group for whom it was desirable to arrange transfer to the United States as soon as possible, presented a large and difficult problem. It was found that patients arriving at base hospitals were often in poor surgical condition as regards drainage, position, and immobilization. It became the special duty of the orthopedic consultant to locate and deal with these patients before convoy lists for evacuation to the United States could be made up. At the Savenay hospital center (Base Hospitals Nos. 8, 69, 88, etc.) and more or less throughout Base Section No. 1 (Base Hospital No. 101, at St. Nazaire; Nos. 11, 34, and 38, at Nantes; No. 27, at Angers) the plan worked out for dealing with these cases was as follows: (1) Cataloguing and inspection every orthopedic patient as he entered the hospital. (2) The written opinion of

[a] The data in this chapter are based on The History of the Hospital Center, Savenay. Part II, 98–146. On file Historical Division, S. G. O.

every medical officer as to the patients that he saw. (3) Centralized operating, splint, and plaster-of-Paris rooms to which patients were brought for treatment. (4) A card-index catalogue, with a follow-up system by which recommendations made by medical officers were checked up and controlled until the patient was pronounced fit for transfer.

The first centralized splint room, established at Base Hospital No. 8, Savenay, about September 1, 1918, proved one of the most helpful features. In the course of a few days it reached a capacity of from 30 to 50 patients daily.

Much has been said and written about the use of plaster of Paris in war injuries. The technique employed at Savenay was as follows: Wounds were carefully dressed, the entire extremity was covered with cotton wadding, and muslin or gauze bandage applied evenly and smoothly; then the plaster was put on firmly but not too tightly; large windows were cut over all open wounds and over patellas and heels; casts were not split. Plaster of Paris was used especially for fractures of the femur, leg, and upper arm.

From September to December, 1918, about 1,000 plaster casts per month were put on and practically all sent to the United States. No complications as to casts were reported and in general the patients were found to have traveled safely and comfortably. For patients who had to have manipulative correction of deformity existing at the time of arrival at Savenay, plaster was the ideal splint because of the better immobilization and protection against motion irritation of injured and infected parts.

The following circular letter indicates exactly how patients were to be cared for at Savenay during September, 1918, and later:

From: The consultant in orthopedic surgery, Hospital Center, Savenay.
To: All medical officers.

In dealing with patients with bone and joint injuries, amputations, tendon injuries, or inflammations, soft-part injuries with contraction or impending deformity, spine injury, flat feet, etc., please observe the following points:

1. Medical officers will be supplied each morning with index cards containing for patients admitted during the past twenty-four hours, blanks for name, diagnosis, etc. Medical officers are to add to these cards by marking under the heading "Condition," whether the patient

1. Requires no splint;
2. Is wearing satisfactory splint;
3. Requires change of splint or operation;
4. Without splint but splint required.

In case of "3" or "4" specify the patient's requirement under the heading of "Notes" or on the reverse of the slip.

2. Amputation cases are to be reported separately on special slips, or brought to the attention of the consultant by reporting patient's name and ward.

3. Under the heading "Diagnosis," the diagnosis number (as indicated on Special Diagnosis Table already furnished) is to be entered, e. g., 17 for GSW elbow joint.

4. The buff cards must be completed and turned in to the orthopedic office on the same day they are received. There must be no exception to the rule.

5. In the case of patients who are to be splinted in the wards the wardmaster's report is to be sent to the orthopedic office as soon as the application is finished.

6. If any patient requires operation recommendation for such operation must be sent to chief of surgical service, base hospital. The medical officer in charge of the ward will be notified as to the place, time, and by whom the operation is to be performed. No operation by any member of the orthopedic staff is to be arranged in any other way.

7. Ambulatory patients requiring splints are to be referred to the splint room for the application of splints or plaster between the hours of 1.30 and 4.30 p. m. daily. All medical officers are requested to accompany and to apply splints and plaster to their own patients if they care to do so. Field medical cards should accompany patients so that proper entries can be made at the time treatment is given.

8. In sending in reports it should be specified in every case whether or not the patient must be detained in the hospital for treatment and if so, for what length of time.

At Savenay the first special wards to be provided were those for fractures of the femur and for amputations. These were provided during September. The obvious advantages of this plan led to the approval of the commanding officer, early in October, of a larger plan, by means of which more than 1,400 beds were set aside in Base Hospital No. 8, with special wards for leg fractures below the knee (64 beds), gunshot wounds and fractures of the upper extremities (256 beds), gunshot fractures of the femur (196 beds), and amputation (250 beds).

The following arbitrary diagnosis table was used to save writing out diagnoses in full:

TABLE OF DIAGNOSIS

10. G. S. W. or other head injuries with paralysis.
11. G. S. W. neck with paralysis.
12. G. S. W. shoulder fracture (including scapula and clavicle).
13. Fracture, simple shoulder (including scapula and clavicle).
14. Fracture, simple humerus.
15. G. S. W. Fracture humerus.
16. Elbow injuries (not G. S. W.).
17. G. S. W. elbow joint.
18. Simple fracture, forearm or hand.
19. G. S. W. fracture forearm, wrist, and hand.
20. Median, musculospiral or ulna nerve injury.
21. Spine disease or injury (not G. S. W.).
22. G. S. W. spine, with fracture.
23. Fracture, pelvis, simple or G. S. W.
24. Fracture, simple, hip.
25. G. S. W. hip.
26. Fracture, femur, shaft.
27. G. S. W. femur, shaft.
28. Fracture, simple, knee.
29. G. S. W. knee.
30. Knee joint injury (not G. S. W. or fracture).
31. Sciatic, external popliteal or other nerve injury, G. S. W. or otherwise.
32. Fracture, leg, simple.
33. Fracture, leg, G. S. W.
34. G. S. W. and other injury, foot and ankle.
35. Flat foot, foot strain, bunions, hallus rigidus, etc.

As a result of the experience in several thousands of cases the suggestions made in the following paragraphs were developed for practical use with just these points in mind and in the same order.

HEAD INJURY, WITH PARALYSIS

Treatment required: Splinting to prevent drop-foot knee contractions, abduction, and flexion deformity of thigh. Splints required right-angle foot and leg splints, double or single plaster-of-Paris spica. The number of this class of cases was 5 per 1,000 total number of battle injuries in the given hospital.

GUNSHOT WOUNDS OF THE NECK, WITH NERVE INJURY, ULNAR PARALYSIS

(Musculospiral paralysis, ulnar paralysis, median paralysis, deltoid paralysis.) Splint required: Hand cock-up splint, airplane splint. In these conditions it is important to bear in mind that many of these nerve injuries

are only partial and become complete in time through failure to splint early. If the necessary nerve and muscle tissues are conserved, during the entire period of convalescence, an entirely unexpected amount of function will be found to be present at the end of treatment. Failure to maintain in relaxation, muscles involved in even temporary paralysis, results in quite unnecessary permanent disability. One of the points to be constantly borne in mind in the splinting of war injuries is that it is necessary to protect against overstretching muscles or muscle groups for which the nerve supply has been temporarily or permanently cut off. This is of the greatest importance in cases which, within two or three months' time, require neuroplastic or tenoplastic operations. The number of this class of cases was 5 per 1,000 total number of battle injuries in the given hospital.

GUNSHOT WOUNDS OF THE SHOULDER, WITH FRACTURE

Immediately upon arrival at base hospitals either the airplane splint or a plaster-of-Paris jacket including the affected arm should be applied. In a considerable number of these cases, arthrodesis of the shoulder is the end to be sought. For this purpose, plaster of Paris is the ideal device. The upper arm should be at an angle of from 50° to 60° from the trunk, the arm carried well forward, the elbow at a right angle, the hand supinated and dorsally flexed. This position should be maintained from 12 to 16 weeks. This gives a very full range of motion for the upper arm and much earlier healing than treatment in any other splint. When preliminary healing with flail shoulder has been permitted arthrodesis of the shoulder should be sought by secondary surgical treatment along similar lines. The number of this class of cases was 5 per 1,000 total number of battle injuries in the given hospital.

GUNSHOT WOUNDS OF THE UPPER ARM, WITH FRACTURE OF THE HUMERUS

Practically all gunshot fractures of the humerus are received at base hospitals in the straight Jones splint, with the elbow straight and the hand pronated. For purposes of transportation and during the first two or three weeks following injury this splint has much to commend it. It is very commonly poorly applied. Enough traction should be used to keep the ring firmly in the axilla and to contribute to the immobilization of the entire arm. Care must be taken to avoid the application of too much traction. Several cases have been seen in which 1 or 2 inches have been added to arms with humerus fractures by excessive traction in the splint. Not very much traction is necessary. Immediately upon arrival at a base hospital the straight splint should be removed and the elbow flexed with the hand supinated. The Jones humerus traction splint may be used as an ambulatory splint or with the patient in bed and the arm suspended. Often plaster of Paris can be used to advantage. There was some disposition to question the propriety of flexing elbows in fractures of the lower third. It is especially important to do so, however, even with fractures in which the lower fragment can not be entirely controlled. Further modification of the arm at the point of callus is easier than if bony ankylosis of the elbow appears. The number of this class of cases was 75 per 1,000 total number of battle injuries in the given hospital.

GUNSHOT WOUNDS OF THE ELBOW

In general, the same remarks apply as for fracture of the humerus. It is important to remember that extremely serious damage to the elbow joint must be considered not as a contraindication to flexion, as has often been the case, but as an indication. Secondary surgery following complete ankylosis of the elbow is sometimes necessary to provide rotation of the forearm. This can be accomplished by removal of the head of the radius to a point below the orbicular ligament. Various operations have been performed for mobilizing stiff elbows. In general, it may be said, however, that for most severe injuries of the elbow joint, ankylosis in the position of election has been proved superior to even the fairly successful mobilized elbow joint. The number of this class of cases was 50 per 1,000 total number of battle injuries in the given hospital.

GUNSHOT WOUNDS OF THE FOREARM, WRIST, AND HAND, WITH FRACTURE

For early treatment three principal considerations are essential: Immobilization, supination of the forearm, and dorsal flexion of the hand. This injury was one of the commonest fractures (200 per 1,000 total battle injuries in the given hospital) and one of the most difficult to care for. In old cases nonunion of the radius and ulna was rather common. Immobilization is the answer. No other splint is so satisfactory for the forearm as plaster of Paris. In wounds of the wrist and metacarpals a straight arm-and-hand splint was commonly used. This splint and the Jones full cock-up splint, except for very short periods, should be entirely discarded. The full cock-up position should be used, but with a splint which permits full flexion of the fingers. If there is a tendency toward contracture deformity of the fingers, they should be kept in the extended position a short time every day.

GUNSHOT WOUNDS OF THE MEDIAN, MUSCULOSPIRAL, AND ULNAR NERVES

The arm and forearm splints required are the same as in gunshot wound of the brachial plexus in the neck. Injuries to these nerves occur either independently or associated with fracture of the humerus. The nerve injury may also be complete division or only a partial division or contusion. The accompanying paralysis in any case must always be splinted in the same way as long as it exists and until complete recovery results either spontaneously or following surgical treatment. Operative reunion of completely divided nerves can be undertaken only after some weeks of sound healing. The rule of the British was 6 to 12 weeks. It was also suggested by the British that 1 to 2 weeks' massage of the wound area as a preliminary to operation would serve to indicate whether or not operative trauma would be tolerated. Extensive loss of nerve tissue opens up also the question of tendon transference in these cases, as does also extensive loss of muscle tissue. Careful splinting after all operations and the best methods of electrotherapy, massage, and vocational therapy must all be employed, particularly in these cases, to obtain the best ultimate result. The number of this class of cases was 85 per 1,000 total number of battle injuries in the given hospital.

GUNSHOT WOUNDS AND OTHER INJURIES OF THE SPINE

The indications in either spine injuries or in secondary Pott's diseases (a few cases of which were seen) are usually for fixation, either in a plaster jacket or on a Bradford frame, for the transportation of these cases. By making use of the retaining straps on a rigid litter these patients can travel quite safely and comfortably. In very few of the cases seen was any immobilization or protection of any kind provided. In a few cases in which adequately early immobilization was used, early recovery from the paralytic symptoms was observed. Laminectomy must be done in carefully selected cases. The number of this class of cases was 10 per 1,000 total battle injuries in the given hospital.

GUNSHOT AND OTHER FRACTURES OF THE HIP

Early and adequate splinting of gunshot fractures of the hip has yielded some of the most brilliant results in the treatment of war conditions. The mortality has been greatly reduced for both transportation and treatment in base hospitals. No other single factor has contributed so much to the satisfactory results as the Thomas thigh traction splint. It is unfortunately true that the efficiency of the splinting has not always been maintained between the front lines and the hospitals farther back. The Thomas splint should be applied and cared for always in the same manner. The introduction of individual methods invariably leads to a loss of efficiency, as patients pass from the hands of one surgeon or hospital to another. The following points must be observed: A long splint and a well-fitting ring must be selected. It must be bent to an angle of 10° to 15° at a point 1½ inches above the level of the knee joint. Having regard for wounds, the adhesive traction bands (of Sinclair glue or moleskin plaster) must include as much skin of the leg and thigh and extend as high as possible. The traction ropes for twisting attached to the lower end of the adhesive, should be of ¼-inch rope or of four-ply muslin fastened very securely into the adhesive, so that it will not give way under a pull of even 15 to 20 pounds. Muslin hammocks of not more than 4 inches in width should be placed across the splint for its entire length at a sufficient tension so that the leg rides well on the top of the splint. The splint is then put on and the traction strap is tied firmly over the lower end with the ring tight against the tuberosities of the ischium. A right-angle foot piece is put on and the foot and knee bandaged in such a way as to put the entire extremity at rest in the splint. The twisting of the traction bands should have attention once or twice daily. The lower end of the splint should be tied to the outer end of the foot of the bed in such a position that the lower end of the femur rotates slightly outward. The foot of the bed should be raised 12 inches so that the patient's body acts as a counterweight to pull against the anchored splint. By following exactly this technique it was possible at the Hospital Center, Savenay, to demonstrate an average gain in length of more than three centimeters in a series of over 300 cases. In dealing with open wounds in this splint, it is only necessary to release one or two of the 4-inch hammocks. Care must be taken so that the entire area of the fracture is not moved or allowed to sag below the level of the

anterior of the femur. In fractures of the neck, as soon as feasible, good traction and slight abduction having been maintained in the meantime, a plaster-of-Paris spica, with full abduction, should be applied. The Thomas double abduction splint should not be used except by those experienced in the use of this particular device. In complete destruction of the neck, with loss of substance, early excision of the head through a posterior incision is advised. Following the operation, also as soon as the wound permits, a plaster spica with full abduction should be used. Departure from the principle enunciated above for special purpose should seldom be made; lowering the foot of the bed or raising the head are only justifiable under exceptional circumstances. The number of this class of cases was 10 per 1,000 total battle injuries in the given hospital.

GUNSHOT AND OTHER FRACTURES OF THE FEMUR

All of the remarks made above with reference to the application of the Thomas splint apply to fractures of the shaft. An astonishingly large number of femur fractures of the shaft apparently well splinted at the front, arrived at the end of 6 to 12 weeks with from 1 to 3 inches of shortening. A large amount of this must be charged to failure to make efficient use of the Thomas splint. This splint, either with or without overhead suspension in the Balkan frame, must be considered to have proven by far the best method of treatment. The number of this class of cases was 75 per 1,000 total battle injuries in the given hospital.

GUNSHOT WOUNDS OF THE KNEE-JOINT

Omitting from the present discussion the question of open or closed treatment of knee-joint injuries at the front, one must consider the treatment of septic knee joints by immobilization or with motion, and by drainage in the later severe septic cases. By the work of Willems it has been adequately shown that certain acute septic knees can be treated to best advantage with adequate drainage and active motion. It is obvious, however, that this motion must be intelligent and carefully controlled. It is not to be construed that such patients may be permitted to travel either from one hospital to another or overseas without such immobilization either in a Thomas splint or plaster-of-Paris splint as to protect against traumatism. Any of the septic cases may require additional drainage. All the methods, including reflection of the patella, have been tried. One of the most valuable incisions for draining the popliteal space was worked out and used. It consists of about a 4-inch incision along the inner and posterior border at the upper end of the tibia. This is followed up through the space under the insertion of the popliteus into the knee-joint and drains one of the most dependent and inaccessible synovial spaces in the joint. This incision may be extended upwards over the back of the internal condyle. By keeping in close contact with the bone, the entire popliteal area can be drained with much less risk to the vessels than through any posterior incision. The number of cases of this class was 25 per 1,000 total battle injuries in the given hospital.

OTHER DERANGEMENTS OF THE KNEE-JOINT

One of the constant orthopedic problems arising out of military service is that ordinarily placed under this rather vague heading. This class of cases, which numbered 10 per 1,000 total battle injuries in the given hospital, includes damage to the external and internal semilunar cartilages, rupture of or damage to the crucial ligaments or the extrinsic ligaments of the knee-joint. Treatment involves modification of boots, removal of loose bodies or of semilunar cartilages and even, in some cases, reconstruction of new crucial ligaments from hamstring tendons. Differential diagnosis of these conditions presents some difficulties. An operation should not be done until not only a diagnosis has been made but also the possibilities as to operative results following operations for comparatively trivial conditions have been seen. The experience of civil practice has shown the wisdom of resection and arthrodesis for prolonged infections which eventuate in tuberculosis.

GUNSHOT WOUNDS OF THE THIGH AND LEG, WITH NERVE INJURY

These patients usually present themselves with foot-drop due to injury of the sciatic or external popliteal. Such cases must always be carefully splinted to maintain the foot at a right angle. For patients able to walk the right angle posterior splint of the British or the modification of the French splint with the double lateral iron outside the shoe should always be used to protect the patient against foot-drop. Walking patients should always wear a simple right-angle splint at night. Injuries of the anterior crural are rarely seen. When found, however, a long splint should always be worn to protect the knee which is inclined to genu recurvation. The number of cases of this class was 50 per 1,000 total battle injuries in the given hospital.

GUNSHOT WOUNDS OF THE LEG, WITH FRACTURE

This was one of the commonest of the war injuries (100 per 1,000 total battle injuries in the given hospital), and one of the most difficult to treat satisfactorily. Adequate fixation with the Thomas splint or with the ordinary posterior thigh and leg splints was rare. Especially was this the case when patients were being moved about. It is especially in this classification that plaster of Paris may be and should be used. It is the only device that uniformly provides length, position, and immobilization.

GUNSHOT WOUNDS OF THE FOOT AND ANKLE

Adequate fixation of these wounds with the foot at right angles to the leg and slightly inverted must be the invariable rule. Practically all of these wounds, even including those of the toes, cause much disability. Where there is extensive damage to the calcaneum or the metatarsus, amputation must frequently be considered. When the angle joint only is involved, astragalectomy with adequate drainage, will often give a good result. After the period of active treatment, the use of right-angle foot splints as either inside or outside irons, or with double lateral irons as so extensively practiced by the British, is to be

highly recommended. These should be used until stability of the foot and ankle is well reestablished. The number of this class of cases was 120 per 1,000 total battle injuries in the given hospital.

SOFT-PART WOUNDS, WITH DAMAGE TO MUSCLES AND TENDONS OF THE UPPER AND LOWER EXTREMITIES

These wounds, especially in the vicinity of joints, contributed a very large share of the serious war wound deformities (125 per 1,000 total battle injuries in the given hospital). It should always be remembered that any deformity of this sort represents healing in malposition that could have and should have been prevented in the first instance by proper splinting. Contracture deformity of the knee from posterior thigh and leg wounds was especially common. This and associated foot-drop may always be prevented by the simple expedient of applying suitable apparatus before malposition develops and continuously until healing is complete.

CHAPTER V

AUTOGENOUS BONE GRAFTS FOR NONUNION IN ATROPHIC LONG BONES AND IN CHRONIC SUPPURATIVE OSTEITIS (OSTEOMYELITIS),[a] FOLLOWING WAR WOUNDS[a]

During the four-year period ending December, 1923, 129 bone-graft operations were performed at Walter Reed General Hospital for conditions resulting from World War wounds followed by severe infection of bone and soft parts, for nonunion, and loss of substance in bones of the extremities. Fifty-two of these were unsuccessful. The majority of these cases were the result of war wounds in which, at the time of injury, severe damage was sustained by the bone as well as its surrounding soft parts. The bone showed marked atrophy and osteoporosis; its osteogenetic power was at a minimum, latent infection was present in the bone and the surrounding scar tissue, and the circulation in both was markedly impaired. In practically all of these cases the fractures were received during the summer of 1918; some even earlier. The majority occurred in France and had active infection in the bone for from four months to two or more years, causing a destructive osteitis, the usual infecting organism being the hemolytic streptococcus. Ordinarily this condition of chronic bone infection has been referred to as osteomyelitis, from which it differs in many respects, but by usage has come to mean the same. Repeated operations for the removal of sequestrum, establishment of drainage, and preparation of the wound for dakinization, further limited the blood supply, increasing scar tissue formation and bone atrophy. Added to this was the atrophy of disuse which further impaired its reparative osteogenetic properties.

As other Army general hospitals closed, many of the failures there, as well as the nonunion cases that were still septic, were gradually transferred to Walter Reed General Hospital, the easier and more successful cases having been cured and discharged. Others were sent in for treatment by the Veterans' Bureau.

In this group, 26 had been grafted elsewhere unsuccessfully; 15 had been plated or wired, and 6 had had some type of "stepping" operation. For a 2-inch loss of substance in a radius, one surgeon had used a toothbrush handle unsuccessfully. Atrophy was probably most marked in the humerus and next in the tibia, and usually where there was loss of bone substance the bone ends were atrophic, rounded off, or pointed. Eburnation in bone ends with pseudoarthrosis occurred in the tibia and bones of the forearm, without loss of substance, and occasionally in the femur and humerus with loss of substance, since there was no second splinting bone to hold the ends apart. This was

[a] The data in this chapter are based on "End Results of One Hundred and Fifty-eight Consecutive Autogenous Bone Grafts for Nonunion In Long Bones (*a*) in Simple Fractures; (*b*) In Atrophic Bone Following War Wounds and Chronic Suppurative Osteitis (Osteomyelitis)," by Maj. N. T. Kirk, Medical Corps, U. S. Army. *The Journal of Bone and Joint Surgery*, Boston, 1924, vi, No. 4, 760–799.

more often the case in the femur than in the humerus, as bone-end apposition was more frequent.

Loss of substance was the rule in this group, the amount varying from a fraction of an inch to 5 inches. The whole shaft of the humerus except 2 inches at each end was destroyed in eight cases. Several cases with 3 inches loss of substance in the tibia were grafted successfully. In a case having a 5-inch loss of substance, the head of the tibia formed the proximal fragment. This case was grafted once elsewhere and twice at Walter Reed General Hospital, all three operations being unsuccessful: the first due to infection and in the latter two operations atrophy and fracture occurred. Eventually the leg was amputated.

No attempt was made to graft in any case until it had been healed for at least six months without signs of infection, unless the roentgenogram was negative for sequestrum or evidence of infection in bone, and only after vigorous repeated massage in the physiotherapy department. If scar tissue was present in skin, it was removed and a skin closure done, at which time any scar tissue in soft parts or about the bone ends was removed. It was found that scar tissue in skin in these cases would invariably break down if at all in proximity to the operative field, and often cause exposure of bone and disaster. If infection followed the scar excision, the graft was not attempted for another six months. If healing was by primary intention, the graft was done four to six weeks later. Even with this procedure, infection caused 22 failures, and 9 other cases were severely infected, but union occurred, although the graft was later removed in 3. Very severe infection causing failure has been encountered after the original wound had been healed one year and no reaction occurred after a preliminary scar excision. There appears to be no assurance as to when all danger from latent infection is past. In the leg it was sometimes necessary to do two scar excisions and skin plastic operations before all scar tissue was removed and there was sufficient healthy skin to cover the bone.

TYPES OF GRAFTS

The types of grafts included inlay, intermedullary, osteoperiosteal, peg (not intermedullary). Grafts of the inlay type included true inlays, outlays, "fish-tail" type, and "massive" grafts. Most of the grafts were cut with the single Albee saw from the healthy tibia. In 1920 and 1921 the crest of the tibia was used in the humerus, radius, and ulna, but this was later abandoned and the graft was taken from the inner surface. The inlay type of graft was always used in the tibia, usually in the forearm, occasionally in the humerus and femur.

The intermedullary type was found best suited in the atrophic humerus. The cortex was so atrophic that there was practically nothing left but the medulla, in which there was an increase in fat. The ends of the bone fragments were cut off and the graft introduced, causing a minimum of interference to the blood supply of the bone by way of the periosteum attached to soft parts. Again, the graft was driven into the medulla of the upper fragment and inlaid into the bone of the condyles and supracondylar region. These

grafts were reinforced by osteoperiosteal grafts wrapped about them and sutured to the periosteum of the upper and lower fragments.

The osteoperiosteal type was used successfully on a fractured patella with nonunion, of four years' duration the result of a gunshot wound. The first attempt in this case was unsuccessful, due to the failure of the absorbable suture to maintain fixation of fragments sufficiently long. A second failure occurred in the use of this type of graft on a fractured graft.

The size of the graft and its contact with healthy bone is essential to its circulation, life, and proliferation. The general rule followed is to cut a graft at least three times the length of the loss of substance to be bridged or of poor bone in which it will be in contact, though it is not always possible to get a graft long enough from the healthy tibia to meet these requirements.[b] At first these grafts were held in place with kangaroo tendon and chromic catgut through drill holes in the side of the trough. It was found, however, that the circulation was so poor that this absorbable material did not absorb but acted as an irritant, causing sinus formation, and was more than once the cause of infection and loss of the graft. The writer has removed it as long as one year after it was placed in the bone. Its use was discontinued and the grafts made self-retaining without the use of ligatures. This was accomplished by cutting the graft to fit snugly, and a half inch longer than the trough in the inlay type, undercutting the ends of the cortex on both fragments and sloping the graft ends from above downward so that they could be wedged under the cortex at both ends. The graft is then fitted in position with one end under the cortex, forced down to position at the other, and then, using a mallet and an instrument with a sharp point and a shoulder, slid down until the lower end becomes fixed under the cortex. This method is now being used in all grafts.

There were eight cases in this series of bone grafts of the tibia operated upon by an associate of the writer in which an entirely different procedure was used; all were successful. He used a small graft cut from the inner surface of the tibia and, after removing all of the endosteum, secured the graft into the fragments without opening the medulla. The graft consisted of periosteum and osteum only and was placed in contact and made self-retaining in the cortex by cutting a wedge, sloping the graft ends from above downward, and sliding the graft in from the side, the end becoming engaged under the notch that had been cut in the cortical bone. Chances of infection were lessened because there was less bleeding, the medulla not being opened; bone growth was slower than in the inlay type, but occurred. He applied his plaster cast before operation and operated through a window in the plaster.

The tourniquet was not used except in operating upon both bones of the forearm when the bloodless method was employed, but it was removed and all bleeding controlled before the graft was put in position. Hemostasis was difficult in these chronically infected cases, due to oozing from scar tissue, but was as complete as possible before closure.

The skin, except when two incisions were necessary in the forearm, was sutured with silkworm gut, a window was cut in the plaster cast two days

[b] The average size of inlay graft used in the tibia for nonunion was 6 by one-half inch; the largest measured 10¾ by three-fourths inch, in a tibia with 3-inch lost substance.

after operation, and the wound dressed daily until all stitches were removed, when the window was filled in with plaster. This was necessary because of possibilities of infection. When infection occurred, stitches were removed and the wound at once dakinized. Nine cases in which infection was severe were saved by this method and many small local skin infections were controlled early and severe infection avoided. Plaster was removed at the end of three months in the tibia and forearm, a roentgenogram taken, and plaster reapplied for another three months in the chronic healed osteomyelitis group. Some required immobilization even longer than this. A well-padded body cast was applied at least two days before a humerus was grafted to insure its proper fitting and setting. The arm piece was put on after the graft was completed. This afforded more comfort to the patient, gave better fixation, and lessened the time on the operating table. In a few cases the arm piece as well as the body cast was applied before the operation and the operation done through a window. This made the procedure much more difficult and was finally abandoned.

The arm was put up in abduction unless the nonunion was between the pectoral and deltoid insertions, when it was adducted and brought across the chest for fear of fracture of the graft from muscle pull.

These casts were not removed until the end of six months.

The following table shows the bone grafted and the results:

Bones	Number	Successful	Unknown	More than one graft
Humerus	30	15	1	4
Radius	15	10		
Ulna	6	5		1
Radius and ulna	5	[a] 3		
Metacarpus	1	5		
Femur	4	2		
Tibia	[b] 45	36		9
Patella	1	1		1
Metatarsus	1	1		
Total	108	78	1	15

[a] Radius only successful in 1 case—represents 5 successful grafts.

[b] Both tibiæ fractured in 1 case.

From this table it will be seen that there were six patients in whom two bones were involved; five involved the forearm, the sixth was a patient having an old gunshot wound with compound comminuted fracture and incomplete union in both tibiæ, lower third. One tibia had previously been grafted elsewhere and had fractured. Both legs presented adherent scars. The patient begged for a double amputation. This was refused. Four operations were done, one at a time, two scar excisions and two inlay grafts taken from the upper third of the bone being grafted. Both were successful. In addition, the patient had bilateral drop-foot, due to loss of muscle and tendon. One side was corrected by tendon suture at the time of the bone graft. In the other the tendons were hopelessly destroyed. The patient is now walking without braces, except a light one to correct the foot-drop in the left leg.

There were two cases in which the shoulder joint, head of the humerus, and from 2 to 3 inches of the shaft had been shot away, along with the deltoid

muscle. In one case the acromion process and outer end of the clavicle were missing. The nerve and blood supply to the arm had not been disturbed. A long adherent scar replaced the deltoid muscle and the long head of the biceps. The arms were useless. After anchoring the remaining shaft of the humerus to the glenoid cavity, at an angle of 90 degrees abduction and in a neutral position as regards flexion and extension, an excellently functioning result was obtained by use of scapular motion in both cases. In the first case, after cleaning out the glenoid cavity, cutting off the end of the humerus, the acromion process was incompletely fractured (green-stick), brought down, and a peg from the crest of the tibia was driven through a hole bored in the acromion, the humeral shaft, and into the glenoid. In the second the glenoid was cleaned out and the humerus cut off and fitted to it. A hole was made 1 inch deep and three-eighths inch square in the glenoid. A 4-inch graft was cut from the tibia, driven into what remained of the medulla of the humerus for 3 inches. The humerus with the protruding 1 inch of graft was then fitted to the glenoid with the hole that had been prepared to receive the graft. The humerus was then anchored to the scapula with a piece of silver wire.

One forearm had nonunion of both bones with marked deformity, pseudoarthrosis, and severe eburnation of the bone ends, with two large adherent scars. The scars were excised, both ends of the bone were resected, and later, using an osteoperiosteal graft on the radius and an intermedullary peg in the ulna, union occurred. In another case there was malunion in the ulna with bad deformity in two directions, and nonunion in the radius, which contained a piece of broken silver wire. The ulnar deformity was corrected by osteotomy and an intermedullary peg, the wire was removed, and a 5-inch inlay self-retaining graft placed in the radius. Excellent bony union occurred in both, correcting the deformity.

Six times the nonunion in the radius was in the lower end, presenting the characteristic radial deviation deformity. This required an osteotomy and shortening of the ulna from an inch to an inch and a half to correct the deformity.

The smallest graft in the series was 1¼ inches long and three-sixteenths of an inch square, and was used to replace the shaft of the second metacarpal bone. The result was excellent. The tendons had not been destroyed, and after a capsulotomy posteriorly of the metacarpophalangeal joint, the soldier was returned to duty with normal function.

One tibia was grafted with a heterogenous graft, taken from the tibia of another patient of the same blood group, after amputation through the middle third of the leg. This was used because of an old healed chronic osteomyelitis in the opposite tibia, and a sliding graft was impossible on the one having the nonunion, there not being sufficient bone. Absorption and infection followed; the osteoclasts appeared to be very active.

One tibia had malunion with a large unhealed scar 3 inches in diameter. The lower fragment was displaced outwardly 20 degrees from the long axis of the upper fragment in the position of weakness for weight bearing. The scar was cauterized with the actual cautery, excised, a correcting osteotomy was performed on the tibia, but there was no attempt at union; some of the bone sequestered. After another scar excision, the tibia was successfully grafted.

the deformity being corrected. Fifteen cases were grafted a second time. Seven were successful; three of these had been unsuccessfully grafted elsewhere, making their third graft. Four were tibias, one was an ulna one a patella, and one a humerus.

Of the eight failures, five had been unsuccessfully grafted elsewhere before, this making the third graft.

The tabulated results of the total series are:

Grafts	129
Successful	76
Per cent	59
Unknown	1
Failures	52
Patients	107

Only cases which had definite bone union and had a functional result on discharge were classified as successful. Patients were not discharged until after there was sufficient bony union in the lower extremity to allow them to walk with the use of a brace only to guard against undue stress, and those of the upper extremity were held for a like period. This period was anywhere from 6 to 20 months after the graft.

Union was never sufficient to allow weight bearing before the sixth month and in some cases not until the ninth and then only with properly fitting braces which were made in our own orthopedic shop. The war demonstrated that gunshot fractures which united without graft required twice the time to form solid bony union as was the case in peace-time fractures, and required splinting or bracing for a like period to prevent refracture or deformity.

The same observation was made in this series of grafts; the period of time required for complete union to occur was from two to three times as long in the chronic osteomyelitis group as in a noninfected group.

Two cases that were originally classified as failures due to infection subsequently returned for reexamination, when solid bony union was found. It is not impossible that a certain number of cases reported here as failures have united since discharge.

The one case carried as unknown left the hospital in plaster and has not been heard of since.

The cause of failure was:

Infection	22
Atrophy	15
Fracture in plaster before seventh month	7
Fracture after seventh month	6
Faulty fixation of patella	1
Death from shock	1
	52

Infection was the cause of the greatest number of failures due, no doubt, to latent infection in the bone and soft parts, rather than to accidental infection at the time of operation. The same technique was employed and the same operators operated upon these cases, as in like operations in simple fractures, yet there were no grafts lost from infection in the simple fractures.

The cause, then, is considered to be latent infection, diminished blood supply in the bone and soft tissues, and the presence of subcutaneous scar tissue and bone atrophy, thereby lowering the vitality of the part. Sequestra not infrequently formed at the end of the fragments along the edge of the trough; apparently the interference with the circulation of the bone in cutting the trough caused its death.

Two sets of instruments were always used when a graft was done, one for the extremity being grafted, and the other for the healthy tibia. Infection was carried into the tibia of the healthy leg once by the use of the same twin saw. Its use was promptly discontinued.

Atrophy was apparently the cause of 15 failures. This may have been the result of using too small a graft with insufficient bone contact to nourish it, improper fixation, or insufficient blood supply and osteogenetic power in the bone which was grafted to keep the graft viable. The failures actually occurred in those cases showing most marked bone atrophy or loss of substance and in cases with some underlying constitutional disease such as tuberculosis and syphilis, or were in generally poor physical specimens.

Fracture of the graft before the seventh month caused failure in seven cases. Atrophy undoubtedly played a part in these. Other factors were muscle action, poor fixation due to atrophy of the soft parts and shrinkage of the extremity in its cast, and to too much activity, carelessness, and non-cooperation on the part of the patient.

There were nine fractures after the seventh month while wearing braces, some of these as late as the ninth month, all due to trauma. All originally had loss of substance of from 1 to 3 inches. All these might readily be classified as successful. One patient discarded his brace and apparently deliberately refractured his graft, as he did not desire his discharge. In three cases the bone reunited without operation, leaving six failures due to this cause.

Two patients were reoperated upon successfully with inlay grafts along the fractured graft; one unsuccessfully, using an osteoperiosteal graft; one continued to run a systolic blood pressure of from 80 to 100 and was refused further operation. Two left the hospital without further operation; one developed a sinus after three months, and the graft was lost through infection the eighth month, due, it is believed, to irritation from the kangaroo tendon ligature.

One failure in a grafted patella occurred, due to absorption of absorbable suture used to hold the fragments in position until consolidation occurred after an osteoperiosteal graft. This case was regrafted, the fragment being held with silver wire. Union occurred, and the knee flexes to 90° and the patient has sufficient power in the quadriceps to go up and down stairs.

There was one death from surgical shock in a graft of the upper third of the femur.

A blood pressure reading was taken during all grafts every 10 to 20 minutes, and a careful check kept on the patient's condition. Shock was much more easily produced than is ordinarily the case, due to the long hospitalization, with absorption of toxins from chronic infection and repeated

operations. When it occurred it was treated with saline intravenously and blood transfusion.

A word about the tibia from which the grafts were taken. As was stated, infection was carried into the healthy tibia once. When the graft is taken from the inner surface, the defect is soon filled in with new bone. The writer has removed a second graft, 8 by one-half inches, six months after the first; the cortical bone did not appear as well calcified, but was thicker than normal. He has removed a third large graft from the same tibia and still found good bone.

When the crest is removed, however, it is not wholly replaced and the patient can easily feel the bone defect with his hand.

All patients, when they again became ambulatory about the third week after operation, were fitted with a tibial caliper which was worn for from 8 to 10 weeks, depending upon the amount of bone removed. Two fractures occurred in this series; one patient, not wearing his brace, got too close to a motor truck, and another fell down a flight of stairs while intoxicated. Both healed without deformity.

CASE REPORTS

Case 1.—A. H. Gunshot wound, left leg, causing compound comminuted fracture, and loss of 3 inches of substance in left tibia, followed by chronic osteomyelitis and marked bone atrophy. A large part of the musculature, as well as of the skin, was destroyed. Two scar excisions and plastic skin closures were necessary before a graft could be attempted. Operation, December 2, 1920, Walter Reed General Hospital. Bone graft 7 inches by one-half inch was taken from the right tibia and inlaid into both fragments and made self-retaining. The graft was covered on three sides at the site of nonunion with skin only, and a small sinus developed, which required operation in July, after which the wound healed. Patient was fitted with ischial caliper in December, 1921. He was discharged October ,1922, with good bony union.

Case 2.—N. W., Pvt., Inf. Gunshot wound of right forearm, causing compound comminuted fracture, nonunion both radius and ulna at junction of upper and middle third, followed by chronic osteomyelitis. There were two large adherent scars, marked deformity, and eburnation of both ends of both bones. Operation, March 5, 1920, Walter Reed General Hospital. Scar tissue excised from skin; the eburnated ends of both bones excised and deformity corrected. A Lane plate placed on radius to keep position. This was removed August 4, 1920, when fibrous union was found to be present. September 23, 1920, operation Walter Reed General Hospital. Osteoperiosteal graft wrapped about the point of nonunion in radius and an intermedullary peg placed in the ulna, both taken from the left tibia. Excellent bony union occurred in the radius and fair union in the ulna. The patient was playing ball with this arm when discharged.

Case 3.—C. B. H. Gunshot wound, right leg, causing compound comminuted fracture and loss of substance in tibia, followed by chronic osteomyelitis. Three-fourths of the breadth of the shaft in the middle third of the tibia was lost. Operation, May 4, 1921, Walter Reed General Hospital. Bone graft 9 inches by one-half inch was taken from the inner surface of the left tibia and inlaid into the normal bone of the upper and lower fragments and outlaid along the 6 inches of the remaining bone in the middle third. Healing occurred by first intention. Immobilization in plaster until February, 1922. Fluctuation was at this time found present and a bloody fluid was removed. The fluctuation recurred and the wound had to be incised and Dakinized. In July, 1922, a skin suture was done, and it healed by first intention. The bone was not infected. Patient discharged with good union, September 6, 1922.

Case 4.—E. R. Gunshot wound, with compound comminuted fracture and loss of substance, both bones upper fourth of left leg, followed by chronic osteomyelitis. In addition, patient had paralysis of the external popliteal nerve. On admission the upper end of both

Fig. 85.—Case 1. Loss of bone substance and bone atrophy

Fig. 86.—Case 1. Roentgenogram 3½ months after graft

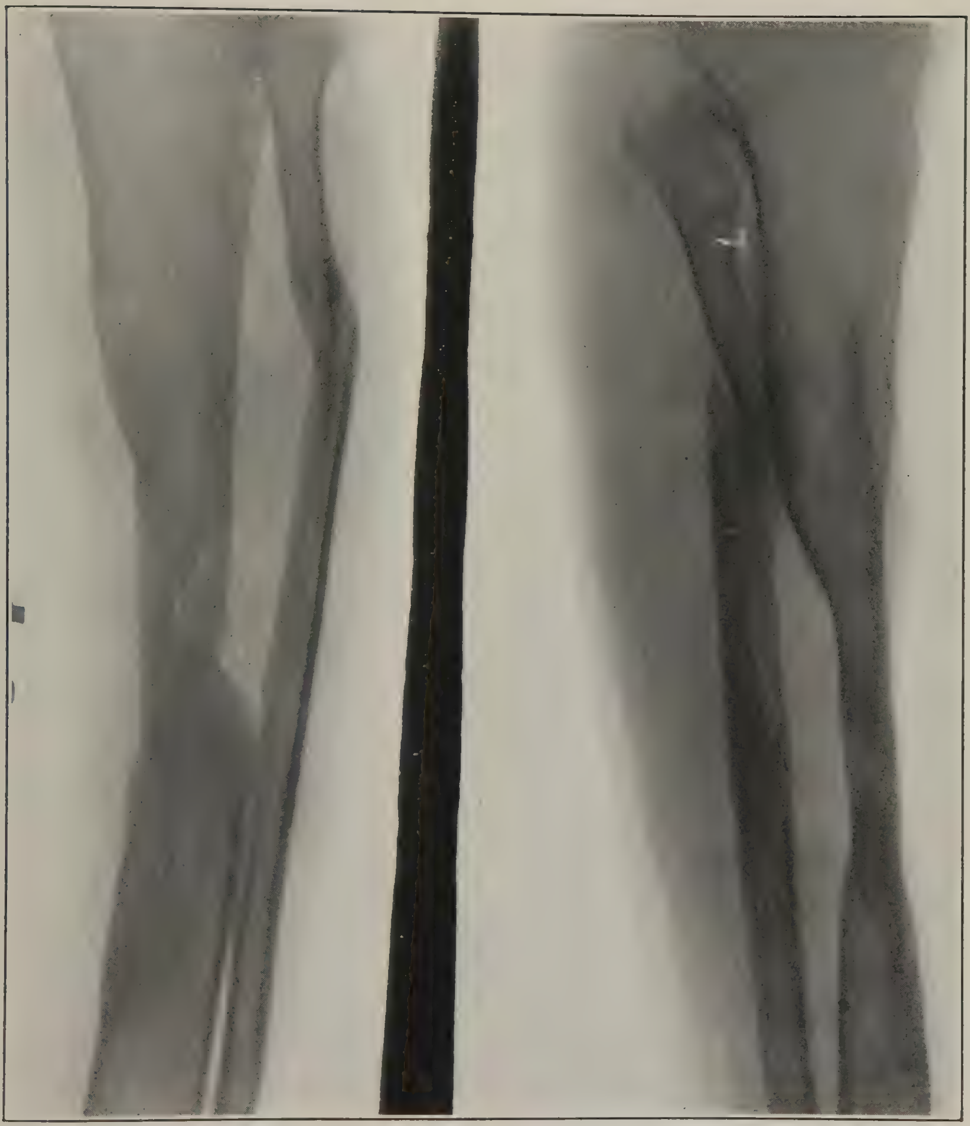

FIG. 87.—Case 1. August 1, 1922. Roentgenogram showing excellent bony union

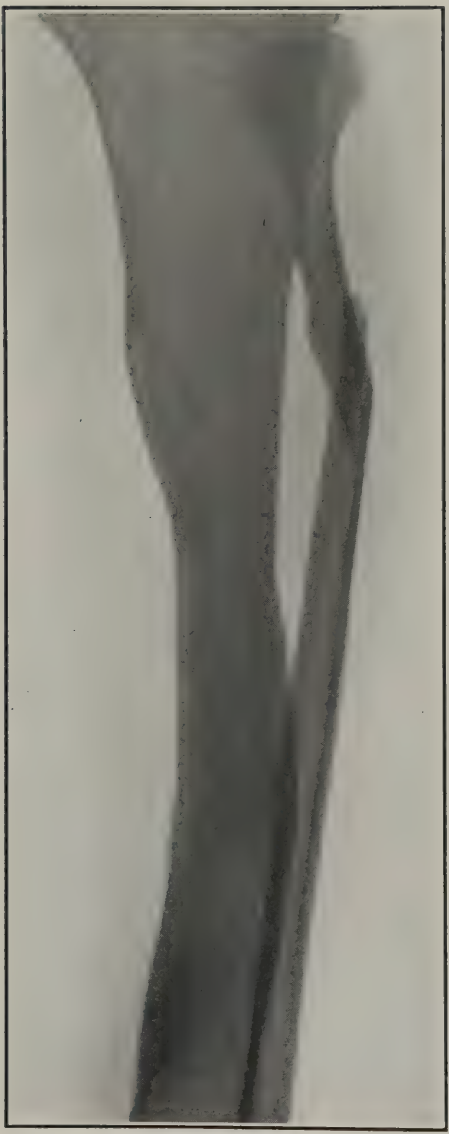

FIG. 88.—Case 1. Roentgenogram, May, 1924, showing hypertrophy of graft in tibia

FIG. 89.—Case 2. Marked deformity and eburnation of bone ends where the pseudarthrosis had occurred

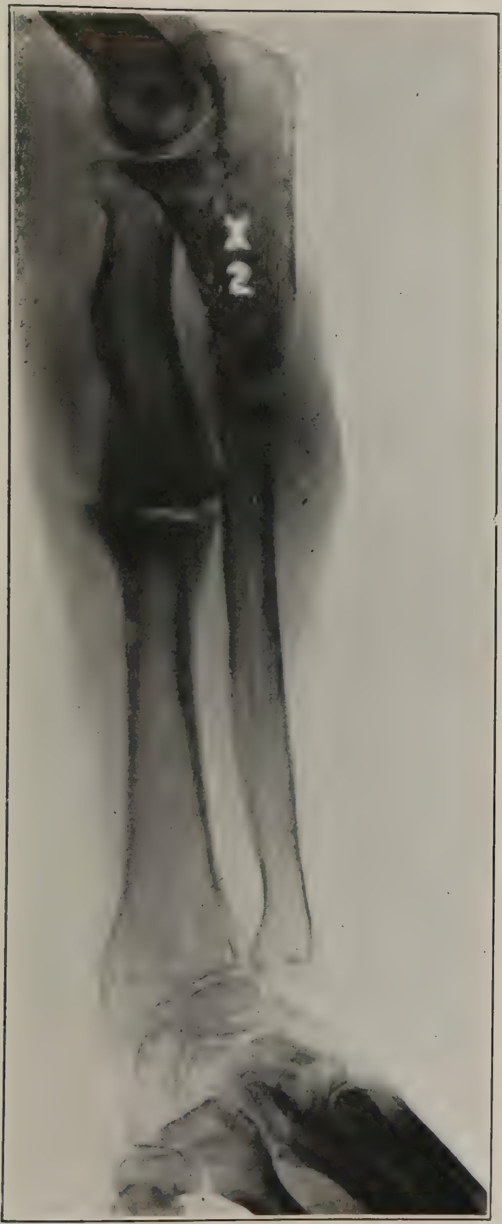

FIG. 90.—Case 2. After resection of bone ends and removal of plate. Deformity corrected

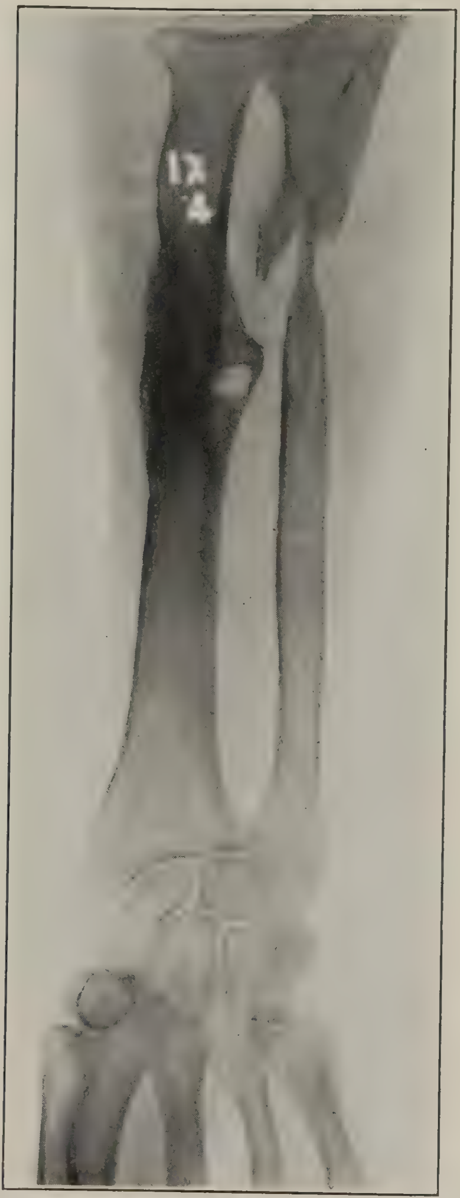

FIG. 91.—Case 2. March 23, 1921. Excellent bony union and hypertrophy of radius

FIG. 92.—Case 3. Roentgenogram, December 10, 1921, showing bone being thrown across between graft and old eburnated bone

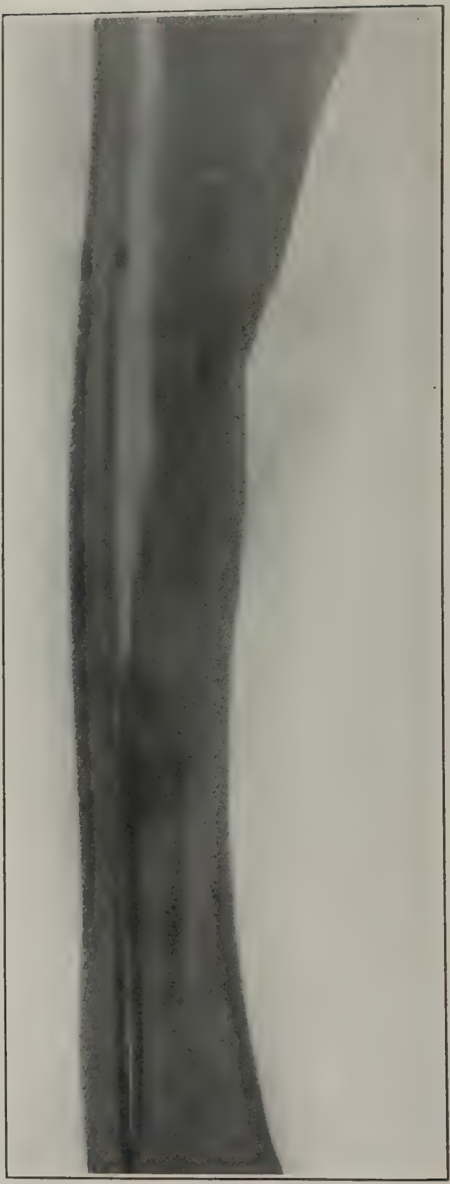

FIG. 93.—Case 3. Roentgenogram, July 28, 1922, 14 months after operation. There is excellent bony union

lower fragments of the tibia and fibula were in apposition with the lower end of the head of the tibia. No attempt at union occurred. Operation, August 31, 1921, Walter Reed General Hospital. Bone graft taken from inner surface right tibia was driven into the remaining head of left tibia and inlaid into the upper end of the lower fragment of the tibia. A small slough occurred in the suture line, which healed. Plaster was removed the seventh month and an ischial caliper substituted. Patient discharge one year after graft with excellent bony union in the tibia, as well as union between the head of the tibia and the shaft of the fibula, which occurred only after the tibia was grafted.

FIG. 94.—Case 4. Condition before operation

CASE 5.—W. J. T. Gunshot wound, with compound comminuted fracture, lower third both tibiæ and fibulæ, followed by chronic osteomyelitis and loss of muscle substance from extensor muscle group in both legs. Before admission patient had had a bone graft in right tibia, which had fractured. He requested that both legs be amputated. This was refused. A scar excision was done on each leg, at Walter Reed General Hospital December 15, 1921, a bone graft 5 inches long was taken from the upper third of the same tibia and inlaid in the lower third alongside old fractured graft, and made self-retaining. A tendon suture of the right extensor tendon group was done at the same time. February 6, 1922, the left tibia was

grafted, using a graft 4½ inches by one-half inch, taken from the upper third of the same tibia, and made self-retaining. Healing of skin was delayed in both cases but no infection occurred. Excellent bony union occurred after each graft.

CASE 6.—D. A. H. Gunshot wound, with compound comminuter fracture, and loss of head, neck, and upper 2 inches of humerus, as well as deltoid muscle, followed by chronic osteomyelitis. The blood and nerve supply to the rest of the arm was not disturbed. The arm hung uselessly by the side. Operation, October 13, 1921, Walter Reed General Hospital. Body cast was applied two days before operation. Arthrodesis left shoulder. Glenoid was cleansed out, the acromion process was ncompletely fractured (green-stick) and brought down; the end of the humerus cut off and fitted to the glenoid in a position of 90 degrees abduction and neutral as to flexion and extension. A bone peg from the crest of the tibia was driven through a hole that had been drilled in the acromion process through the upper end of the shaft of the humerus and into the glenoid, fixing the humerus in position. The armpiece of the cast was applied. The cast was removed at the end of six months and good bony union was found. The arm was kept on an airplane splint for four months. Patient discharged with good scapular function.

FIG. 95.—Case 4. Solid bony union January 17, 1922, five months after graft

CASE 7.—W. H. M. Gunshot wound, with loss of head and upper fourth of shaft of humerus, acromion process, and outer end of clavicle. This was followed by chronic osteomyelitis. The deltoid muscle and long head of the biceps was replaced by scar tissue; the circulation and musculature of the rest of the arm was normal. The arm hung uselessly by the side. Operation, November 9, 1922, Walter Reed General Hospital. Arthrodesis of left shoulder. The glenoid was cleaned out; the upper end of the humerus sawed off. A graft 4 by 3.8 inches was taken from the inner side of left tibia and fitted in a hole 1 inch deep made in the glenoid; removed and driven into the medulla of the humerus. The humerus, with the protruding 1 inch of the graft, was then fitted to the glenoid and its cavity. Through a drill hole in the shaft of the humerus and the coracoid process, a silver wire was passed, securing the humerus to the scapula. Immobilization in plaster with the humerus at 90 degrees abduction and in a neutral position as regards flexion and extension. Body cast was applied two days before operation and armpiece at time of operaion. Five months after arthrodesis, plaster was removed and excellent union was found to be present. Discharged the ninth month with excellent scapular motion.

CASE 8. L. E. Gunshot wound, sustained in action, causing compound comminuted fracture and loss of substance middle third right humerus, and paralysis of musculospiral nerve. There was also a chronic osteomyelitis. Before admission humerus was "stepped"

and a 4-inch bone peg introduced into medulla, followed by nonunion. Operation, April 20, 1922, Walter Reed General Hospital. Intermedullary bone graft 6 by ½ inches taken from the right tibia, made self-retaining in medulla. Cortex of fragments had consistency of an eggshell. Cast removed at end of six months, wound having healed by first intention. Roentgenogram showed good bony union. Discharged July, 1923.

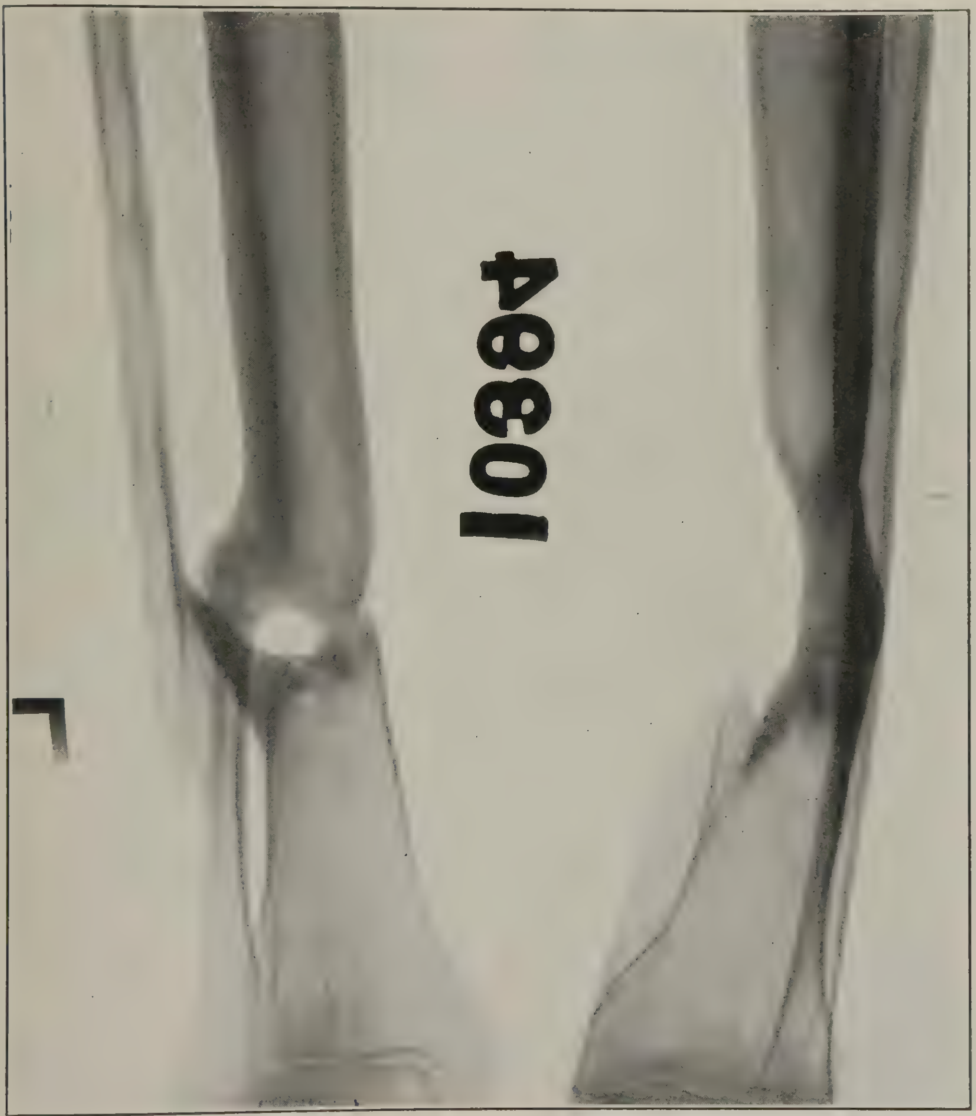

FIG. 96.—Case 5. Anteroposterior view of both tibiæ before bone graft

CASE 9. O. P. Patient sustained, along with other injuries, a gunshot wound causing compound comminuted fracture of the right patella. On admission in August, 1922, there was union between the two upper fragments of the patella and separation of some 2 inches between the upper and lower fragments. Knee flexed to about 45°; muscle power in quadriceps was poor. Operation, September 1, 1922, Walter Reed General Hospital. Scar tissue was removed from between fragments, which necessitated opening knee joint; patella

FIG. 97.—Case 5. Right tibia four months after graft

FIG. 98.—Case 5. Left tibia four months after graft

was held in position with chromic catgut, using a circular purse-string suture and suturing the lateral capsule. An osteoperiosteal graft was placed over and in contact with the anterior bony surface of both fragments. The cooperation of this patient was poor. The absorbable ligatures did not hold and the fragments separated.

Reoperation, December 4, 1922, Walter Reed General Hospital. The same procedure was followed as in the first operation, except that the patella was drilled and two pieces of silver wire used for fixation through the drill holes. A new osteoperiosteal graft was

FIG. 99.—Case 6. Roentgenogram showing loss of bone substance before operation

placed in contact with the anterior surface of the patella and a third piece of silver wire run through the patella tendon and the insertion of the quadriceps tendon, reinforcing the fixation. Excellent bony union occurred, and when the patient returned in January, 1924, to have a piece of the silver wire, which was broken, removed, he had solid bony union, 90° motion, and sufficient power in his quadriceps, to go up and down stairs.

CASE 10. A. B. L., private, Infantry. Gunshot wound of right hand causing compound fracture of second, third, and fourth metacarpal bones, followed by mild infection and loss of shaft of second metacarpal July, 1922. Operation, March 21, 1923, Walter Reed General

Fig. 100.—Case 6. Good bony union six months after arthrodesis

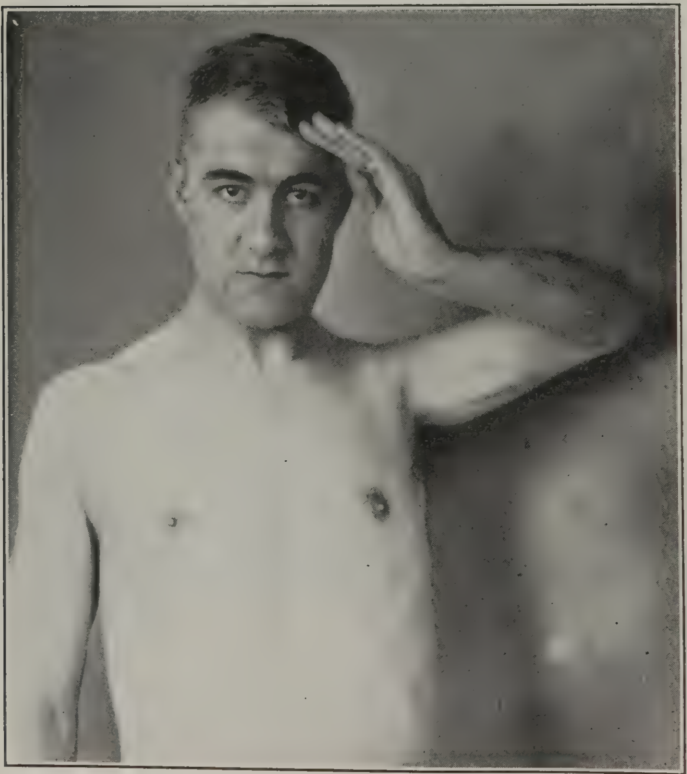

Fig. 101.—Case 6. Photograph showing function

FIG 102.—Case 7. Roentgenogram before operation, showing loss of substance

FIG. 103.—Case 7. Union five months after operation

Hospital. A bone graft 1¼ inches by three-sixteenths of an inch square was driven in a hole made in what remained of the base of the second phalanx and likewise introduced into the proximal end of the remaining shaft and head. Graft was self-retaining. Solid union occurred in two months, with union in the fractured third and metacarpal as well. July, 1923, a capsulotomy of the posterior capsular ligament of the metacarpo-phalangeal joint was performed, followed by normal function in the hand, there having been no injury to tendons. Returned to duty October, 1923.

Case 11. J. F., captain, Infantry. Gunshot wound, with compound comminuted fracture and loss of substance, right tibia, lower third, followed by osteomyelitis. Prior to admission,

Fig. 104.—Case 7. Photograph showing function

one bone graft had been done which was lost through infection. A large scar was removed, Walter Reed General Hospital, and a plastic closure of skin done. Operation, December 1, 1922, Walter Reed General Hospital. Bone graft 10½ inches by three-fourths inch square taken from left tibia. The lower end was driven into the cancellous bone of the lower fragment. The upper end was inlaid into the upper fragment and the end of the graft fixed under the cortex, making it self-retaining. Patient was allowed to walk beginning the ninth month, wearing an ischial caliper. He was discharged December 2, 1923, with excellent bony union.

Case 12. I. K. Gunshot wound causing compound comminuted fracture, 2½ inches loss of substance, lower third left tibia. Operation, April, 15, 1920, Walter Reed General Hospital. Sliding graft brought down from the upper fragment; bone held in place by kangaroo tendon. Periosteum sutured with catgut. Operation was followed by superficial infection, which healed. January 13, 1921. Patient fractured graft nine months after operation. Plaster cast applied and later a tibial caliper. Discharged January, 1922, wearing brace; clinically

FIG. 105.—Case 7. Another view showing function

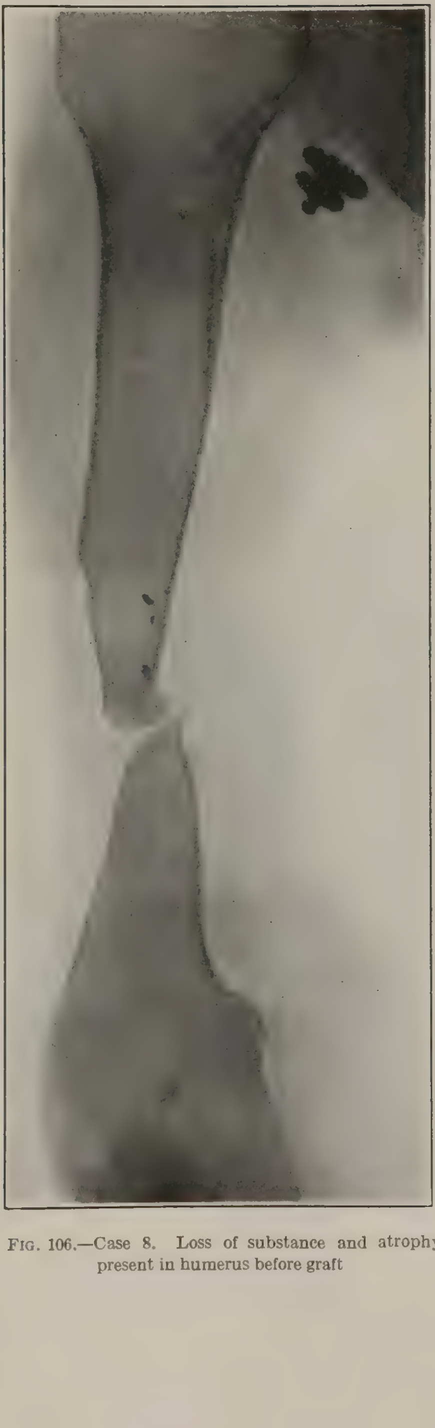

FIG. 106.—Case 8. Loss of substance and atrophy present in humerus before graft

FIG. 107.—Case 8. Excellent bony union at end of six months

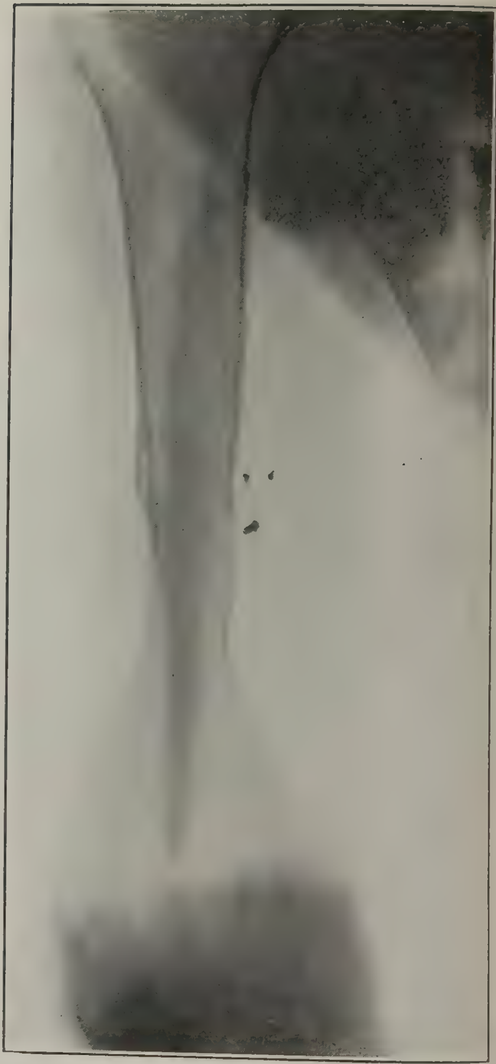

FIG. 108.—Case 8. Another view showing excellent bony union at end of six months

union was present. Returned for examination August 12, 1922, when there was solid bony union; more bone proliferation at the site of the fractured graft than anywhere else along the graft which bridged the loss of substance.

CASE 13. J. C. K. Gunshot wound, sustained in action, causing compound comminuted fracture, and 3 inches loss of substance upper third left tibia, followed by chronic osteomyelitis. Operation, August 30, 1921, Walter Reed General Hospital. Bone graft, 7 inches by one-half inch, taken from inner surface right tibia, inlaid into both fragments and fixed with two kangaroo ligatures. Wound healed by primary intention. Roentgenogram November 17, 1921, when the original plaster was removed and replaced showing graft in excellent condition. Graft was fractured in plaster some three weeks later. Immobilization in a walking plaster cast or on an ischial caliper until May, 1923. Roentgenogram showed

FIG. 109.—Case 9. Lateral view showing comminuted fracture of patella and separation of fragments

FIG. 110.—Case 9. Union present January, 1924

an attempt at union, but a pseudarthrosis occurred. May 15, 1923. A second bone graft was done; a graft 7½ inches by ⅜ inch taken from the right tibia was inlaid into both fragments and outlaid along fractured graft, after freshening graft. The ends of the graft were fixed under cortical bone, making it self-retaining. Roentgenogram in August, 1923, three months after graft, showed union in the old fractured graft, and the new graft in excellent condition. Plaster was removed at this time and ischial caliper fitted. Patient discharged in January, 1924, with excellent bony union.

CASE 14. C. W. Gunshot wound, causing compound comminuted fracture of tibia, right, and loss of substance lower third, with a chronic osteomyelitis. The left leg had been amputated through the middle third as the result of a gunshot wound. Operation, August 30, 1920, Walter Reed General Hospital. Bone graft taken from the upper third of the same tibia,

FIG. 111.—Case 10. Roentgenogram showing loss of substance and deformity

FIG. 112.—Case 10. Two months after graft—deformity corrected, with bony union

consisting of periosteum and osteum or cortical bone. A trough was made in both fragments, without opening into the medulla, with a notch cut in each end. The graft ends were sloped from above downward and the graft pushed in from the side, the ends fitting snugly in the notches in the cortical bone. The leg was immobilized in plaster before operation and the operation was done through a window in the cast. Solid bony union occurred, although the proliferation in the graft was slow. Patient discharged March, 1922.

Case 15. H. W. Gunshot wound, with compound comminuted fracture and loss of substance and chronic osteomyelitis, lower third of both bones, right leg, 1½ inches above

Fig. 113.—Case 10. Showing function on completion

Fig. 114.—Case 10. Another view showing function on completion

the ankle joint. Patient had had an unsuccessful "stepping" operation before admission. Two large scars were excised, one on the outer and the other on the inner surface of the leg before graft. Operation, May 19, 1922, Walter Reed General Hospital. Bone graft 4½ inches by one-half inch taken from the inner surface of the left tibia. The lower end driven into a hole centrally placed in the lower fragment of the tibia to the depth of 1¼ inches, and inlaid into the upper fragment, the end of graft being fixed under the cortex, making it self-retaining. Excellent bony union occurred in the tibia, and in the fibula as well. Patient discharged wearing brace in May, 1923. He is now wearing no support.

FIG. 115.—Case 11. Roentgenogram showing loss of substance

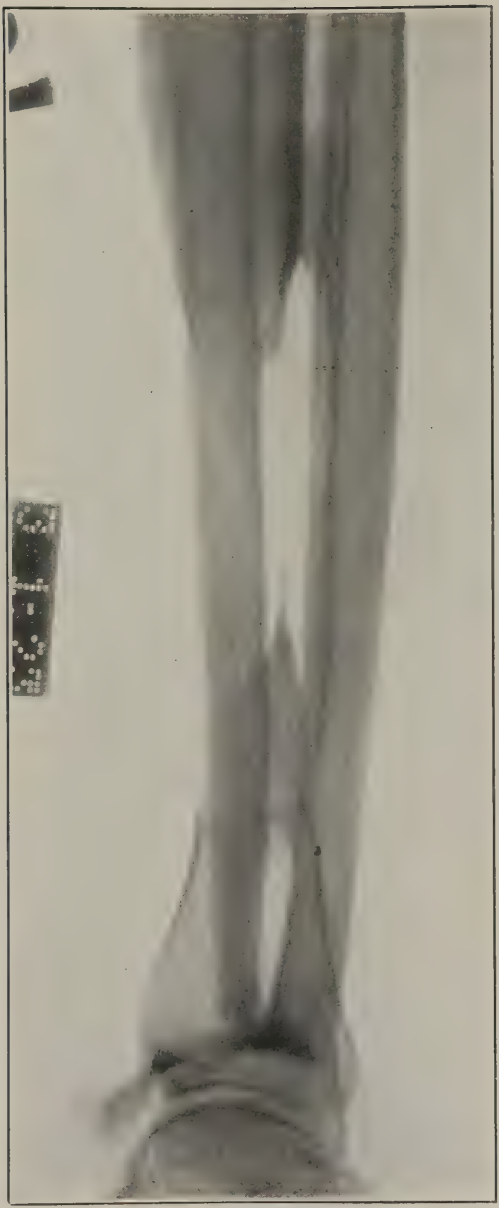

FIG. 116.—Case 11. Roentgenogram three months after graft showing excellent condition of bone

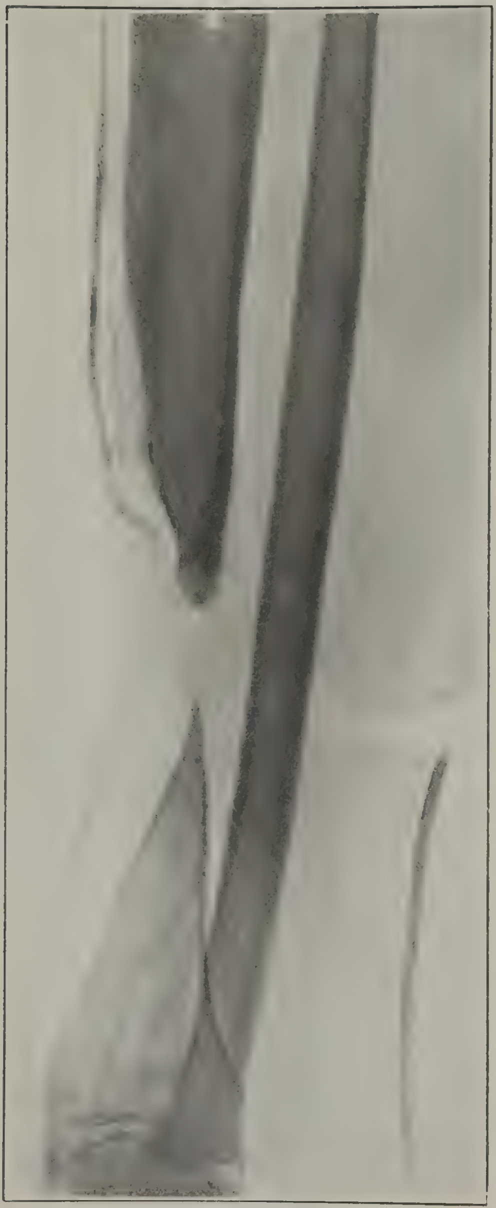

FIG. 117.—Case 12. Roentgenogram showing loss of substance

FIG. 118.—Case 12. Roentgenogram three months after graft

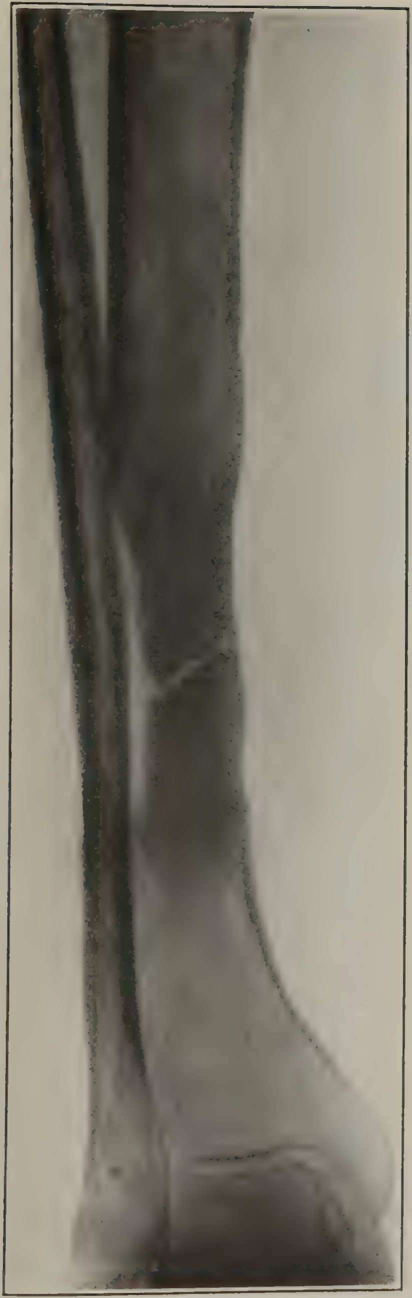

FIG. 119.—Case 12. Linear fracture ninth month

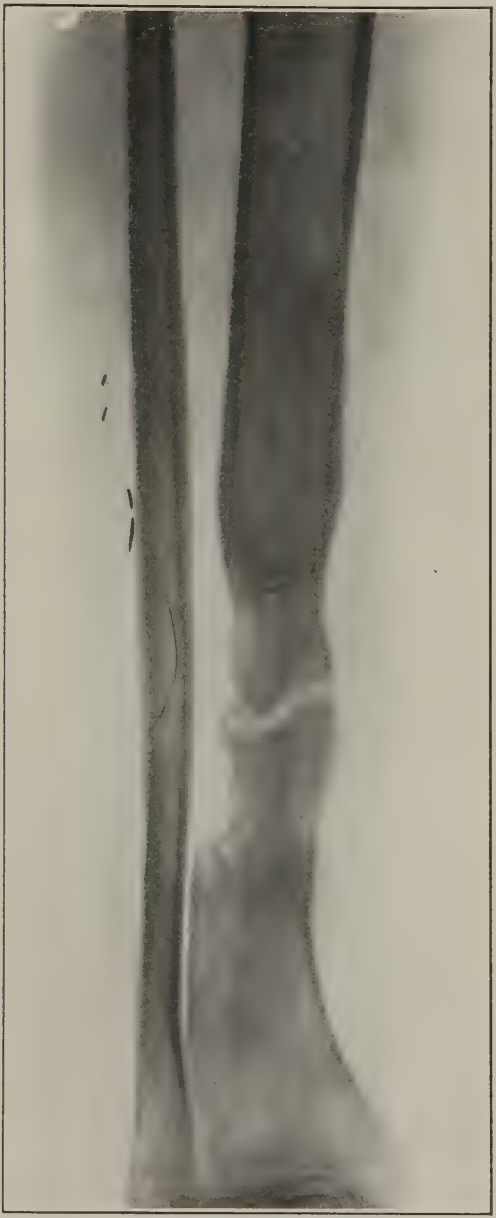

FIG. 120.—Case 12. Note absorption two months later

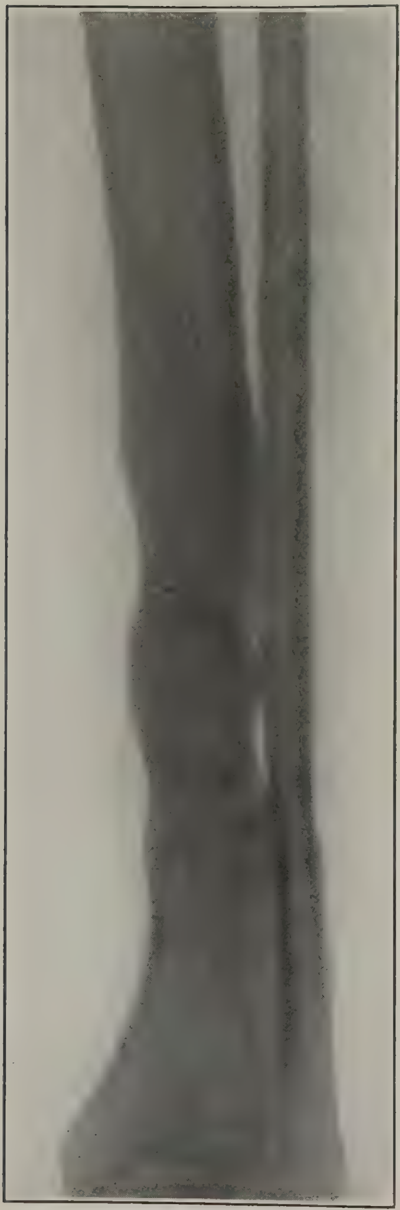

FIG. 121.—Case 12. Solid bony union 19 months after fracture

FIG. 122.—Case 13. Roentgenogram November 17, 1921, fracture of first graft during fourth month and loss of substance bridged by graft

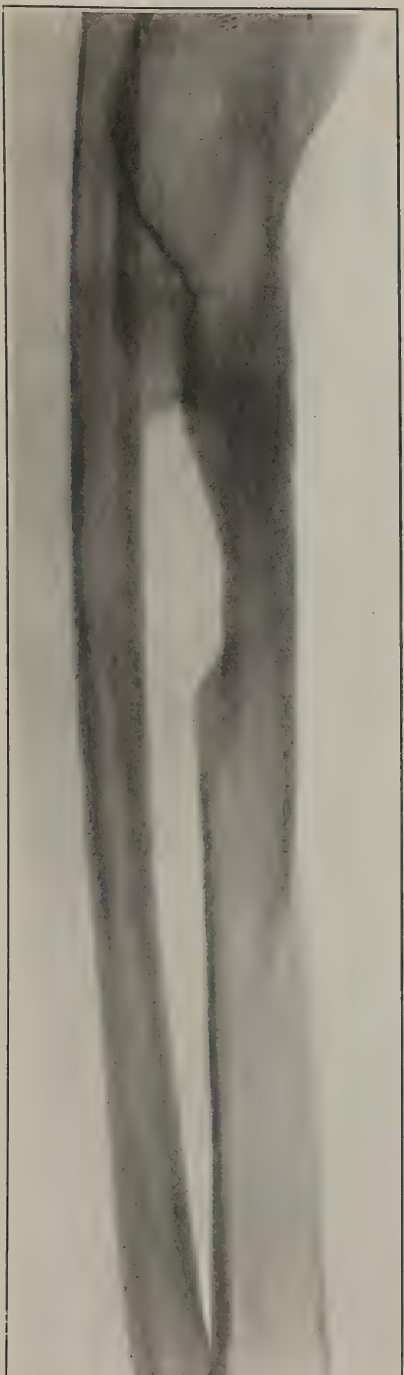

FIG. 123.—Case 13. Excellent union in old fracture in original graft and in new graft

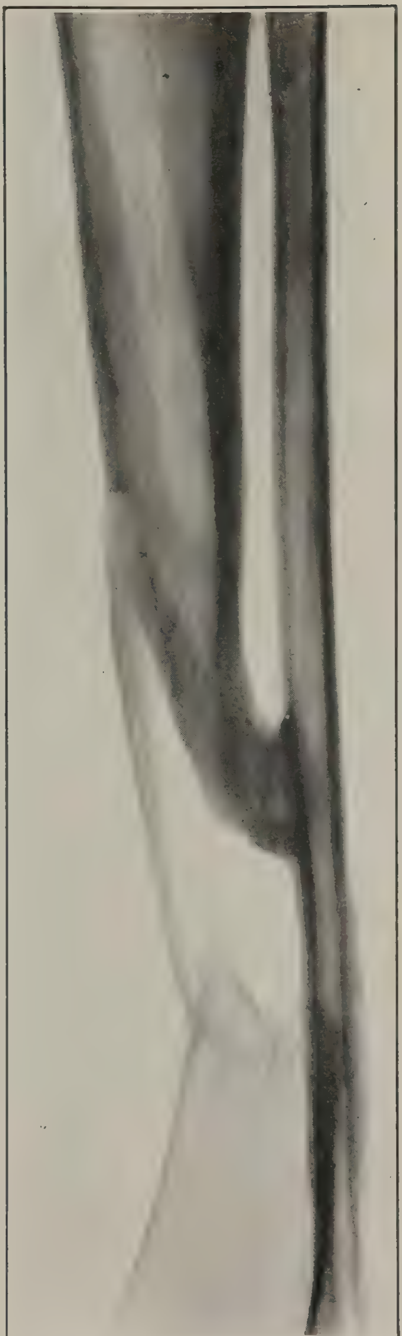

FIG. 124.—Case 14. Roentgenogram of graft six weeks after operation

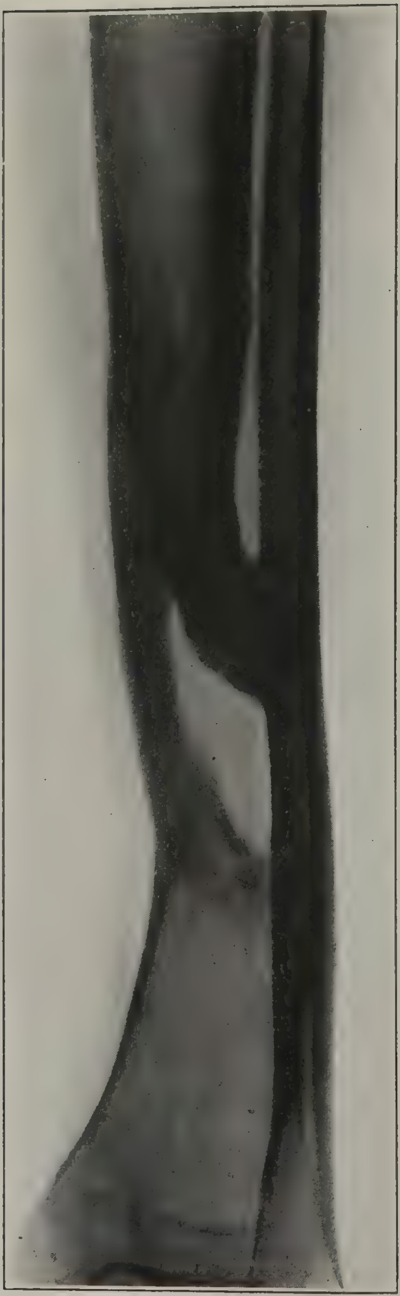

FIG. 125.—Case 14. One year after Figure 124, or 13½ months after operation, showing proliferation which had occurred in graft which bridged loss of substance

FIG. 126.—Case 15. No attempt at union in old fracture. Note proximity to ankle joint

FIG. 127.—Case 15. Lateral roentgenogram three months after graft

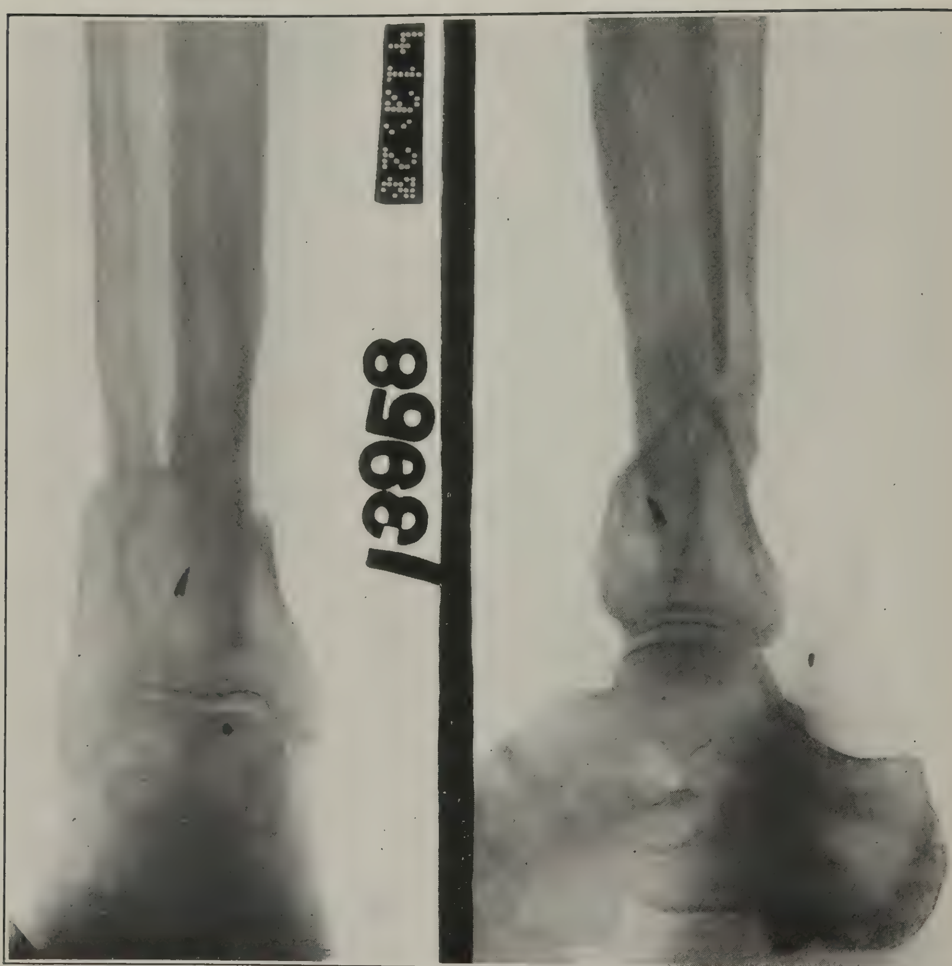

Fig. 128.—Case 15. Roentgenogram 11 months after graft. Outline of graft can barely be distinguished. Note union in fibula

CHAPTER VI

AMPUTATION SERVICE, A. E. F.

ORGANIZATION AND DEVELOPMENT

It was recognized at an early date by the chief surgeon, A. E. F., that the proper management of amputation cases constituted a problem for which special provision ought to be made. This was in conformity with the advice of the senior consultant in orthopedic surgery, A. E. F., who had had special opportunities for acquiring knowledge of the various orthopedic problems encountered in France and Great Britain, prior to our entrance into the war. The first step toward meeting this problem was taken in August, 1918, when, in an order which defined the responsibilities of the general and special professional services, the supervision of amputation cases was assigned to the division of orthopedic surgery.[1] Foreseeing the need of a special amputation service, the senior consultant, orthopedic surgery, immediately set machinery in motion, looking toward the training of a medical officer for this special type of work. Facilities for study were available in the bureau of artificial limbs of the American Red Cross in Paris and through the cooperation of the Allied Governments these facilities were extended to the chief amputation centers in England, Belgium, France, and Italy. Ample opportunity thus was provided for the acquisition of familiarity with all aspects of the amputation problem.

It soon proved that the chief difficulty in the way of providing proper treatment for this important group of cases was the general lack of understanding among military surgeons of the functional requirements in amputation cases. An amputation stump is useful only in the light of the prosthetic appliance which can be worn and of the degree of functional restoration obtained by its aid. Therefore, it is evident that the entire treatment, from the amputation itself, up to and including the fitting of the artificial limb, must be planned with a clear vision of the end result which may be obtained, and with knowledge of each and every danger which must be avoided in order to achieve this ideal. Familiarity with the functional value of amputations at different levels, with the physical requirements of a good stump, and with the different types of prosthetic appliances, is essential to the attainment of this goal.

The opportunities for acquiring this knowledge prior to the war were few and what there were had generally been neglected. Both in England and in France, the need for improvement in the treatment of amputation cases was forcibly brought home, early in 1915, when end results in the early war amputation cases began to be viewed. Many of these cases were in lamentable condition. The vast majority presented fat, congested stumps, with powerless muscles and serious joint contractures. Many had lost important segments of their limbs, due to the mistaken notion that a longer stump would be an incumbrance; and many others had to undergo reamputation and to lose

valuable segments which might otherwise have been saved had suitable treatment been applied. A large number had to go back to the hospitals for long periods of treatment before artificial limbs could be fitted. All made very slow progress and some never succeeded in learning to walk.

It was in order to avoid similar results in the American Expeditionary Forces that the senior consultant, orthopedic surgery, planned to organize a special amputation service through which all amputation cases would pass before being evacuated to the United States.[2]

It was not until April, 1918, that American battle casualties occurred in sufficient numbers to justify the organization of an amputation service. At this time a small beginning was made at Base Hospital No. 9, Chateauroux, France.[3] All amputation cases were segregated in special wards, a gymnasium was established and a prosthesis shop organized. By July the service had expanded to 120 beds.

It had been the intention to have all amputation cases pass through this center. This plan proved impractical, however, when casualties began to occur in large numbers. Following the American battle activities along the Marne there was a sudden great influx of wounded into the base hospitals, American Expeditionary Forces, and some of the amputation cases were evacuated to the United States without receiving special care. To prevent a similar happening in the future the amputation service was transferred, in July, 1918, to Base Hospital No. 8, at Savenay.[2]

This location was selected because of its designation as the main distributing point for the evacuation of the wounded to the United States. From August, 1918, until the signing of the armistice, no cases were evacuated without going through the hospital center at Savenay. All cases of amputation, therefore, could be seen and special treatment instituted when necessary. Early in 1919, the hospital centers at Bordeaux and at Brest also were designated as points of evacuation,[4] and in order to meet this situation it was necessary to organize special amputation services at these points. Medical officers who had received training at Savenay were available for duty elsewhere and little difficulty was experienced in supplying an experienced personnel. Prothesis shops also were organized and equipped at these points.

FUNCTIONS

The basic idea underlying the organization of an amputation service was to provide a center where the special problems encountered in the treatment of war amputations would be understood and where all facilities would be available to solve these problems with a view to the ultimate recovery of the maximum degree of function. Since it was the general policy that reconstructive surgery in totally disabled cases would be deferred until arrival in the United States, the functions of the amputation service consisted essentially of the following: First, to provide proper surgical, physiotherapeutic, and prosthetic treatment for amputation cases. Second, to gather information as to proper methods of treatment, and to spread this knowledge among the surgeons of the American Expeditionary Forces. Third, to prepare cases for evacuation to the United States, and to insure their arrival there in the best possible condition.

The first function had to do with the actual treatment of the patient, provision for which was made by the organization of three departments—surgical, physiotherapeutic, and prosthetic. The surgical department naturally was the most important; its work was essentially the same as that of any other surgical organization, including operating, ward dressing, and records. Physiotherapy was under the direction of an athletic instructor of great ingenuity who conducted daily classes for the ambulatory cases. The men were put through stump drills, which were exceedingly valuable both for strengthening weak muscles and for teaching balance. This instructor also conducted classes for the men who had been fitted with provisional legs, and much of the success attained here was the result of the training in walking which he gave these patients. In addition, a certain number of reconstruction aides attached to the service administered massage and exercise to the bed cases. The prosthesis shop was under the direction of a sergeant, first-class, Medical Department, who was an artificial limb maker by trade. He quickly learned to make the plaster of Paris sockets for the provisional legs, and as the demand for appliances increased, trained others of the hospital detachment in the work so that there was never any delay in supplying apparatus. The skeleton legs, complete in every detail except for the socket were supplied by the American Red Cross.

The second function, that of disseminating knowledge of proper methods of treatment and of the common mistakes that were being made, was taken care of in two ways: By written reports to the senior orthopedic consultant; by personal visits to most of the hospital centers in France where opportunity to talk with the officers actually engaged in treating the cases proved most helpful. All amputation cases received at the hospital center, Savenay, were inspected upon arrival and careful note made of their condition.[2] When there was evidence of improper treatment, this was checked against the hospitals from which such cases had come, and thus it was possible at the end of every month to send full reports to the senior consultant who could make such use of the information as he deemed proper.

The third function of the amputation service was to prepare cases for evacuation to the United States and to insure arrival there in good condition. This was chiefly a matter of judgment and policy in selecting cases for evacuation, since by virtue of authority vested in the local orthopedic consultant no orthopedic patient could be evacuated without his approval. Such a superabundance of transportable patients was always available that it was necessary merely to make a systematic effort to keep them listed in order to be able to hold the nonevacuable cases for treatment.

TECHNIQUE OF AMPUTATIONS

In order to understand the special problems encountered in the treatment of amputation cases in the American Expeditionary Forces and the work of the amputation service, it is necessary to review the surgery of military amputations from the time when the limb was removed to the period of convalescence when it was possible to evacuate the patient to the United States.

IN THE ZONE OF THE ADVANCE

In considering the technique of amputations when performed in the zone of the advance, it is important, first of all, to stress the subordinate rôle which military surgery necessarily occupied in relation to military tactics. Primarily, military surgery had to be adapted to the varying conditions of military activity. With stable trench warfare the casualties were not numerous, and aside from raids and local actions the facilities of the evacuation hospitals were not strained. During such periods it was possible to give each case individual attention and careful after treatment, and special cases could be kept for considerable periods without evacuation. In periods of battle activity conditions were quite the reverse. The influx of casualties was enormous, the demand for beds quite in excess of the possibility of supply, and all hospital facilities were strained to the utmost. Each case had to be treated with a view to immediate evacuation, and the surgical procedures had to be adapted to meet this need. Further, because of the difficulty of evacuating the wounded from the field of battle under intense fire, the time between receipt of injury and of reaching evacuation hospitals in given instances was usually much greater than in quiet times. Contaminated wounds often became infected wounds before they reached the hands of the surgeon, therefore different operative procedures had to be employed. In such cases the prime endeavor was to obtain adequate drainage.

In respect to amputations, this fundamental rule of military surgery was strikingly illustrated. During the periods of quiet in the interval between February 5, 1918, and June 1, 1918, along sectors of the front occupied by American troops, the surgeons of the evacuation hospitals worked under almost ideal conditions. Postoperative cases could be followed for as long a period as was necessary before evacuation. Débridement, with closure by primary, delayed primary, or secondary suture, applied even to amputations. The amputation usually was performed at the level of the wound or immediately above it, with careful excision of all soiled, damaged, or devitalized tissue. Flaps were formed, not according to the classic modes of amputation, but in the way they could best be otbained from the sound tissues of the limb, with the view to conserving the greatest length of stump. If the time since injury was short and the amount of soft-part damage was well localized, it was occasionally possible to close the wound by primary suture. The more common procedure was to fix the flaps in eversion, leave the wound open, and await developments for 24 to 48 hours. At the end of this time the wound was carefully dressed and bacterial examination made. If the condition of the wound appeared favorable, the flaps were then drawn together and sutured (delayed primary suture). If, instead, there was suggestion of infection, the wound was left open and Carrel-Dakin treatment instituted. A certain percentage of stumps treated by the latter method were closed at the end of 12 to 21 days by secondary suture; the remainder were evacuated and went on to cicatrization, later requiring some type of reconstruction operation.

In periods of battle activity the operative procedure was quite different: amputation cases had to be evacuated almost immediately. It had been shown that this immediate secondary evacuation could be done with little risk to the

patient if the wound was left open. The great danger was infection, especially of the anaerobic type. Cases could not be watched carefully when being transported on a train, and in the case of a partially sutured stump or of one with flaps, even though these were not closed, infection might develop and assume fatal proportions before the patient reached a hospital where proper treatment could be instituted.

It was to meet such a situation that the flapless amputation, unfortunately misnamed the guillotine amputation, had been devised by the surgeons of the Allied Armies early in the war. The skin was divided by a circular incision at the lowest possible level, taking into consideration the condition for which the amputation was performed. The skin was allowed to retract and then the fascia and outer layer of muscles were sectioned at this level and in turn allowed to retract. The inner layer of muscles was then cut and the bone was in turn divided at a still slightly higher level. When the amputation was completed the cut surface was in the shape of a slightly inverted cone or if the retraction had been great, a flat surface.

The reproach which has been directed against this operation is not so much against the flapless amputation itself as against the surgeons who misunderstood it and performed it as a guillotine division of the limb. By the latter method no allowance was made for retraction and upon the completion of the operation the wound appeared as a conical surface with the bone protruding at the apex and the skin margin representing the base. By this method there was an unnecessary sacrifice of soft parts. Undoubtedly better results might have been obtained if more heed had been given to the conclusions reached by the Interallied Surgical Congress at its meeting in 1917 which, in so far as concerns amputations, are as follows:[5]

> Primary amputations or those delayed 24 to 48 hours will be made as nearly as possible at the site of fracture by simple section of the soft parts or with slight trimming of the bone; in less grave cases the amputation will be made as near as possible to the level of the fracture.
>
> Amputation for infection will be done by simple cross section or with very short flaps fixed in eversion. The stump will be regularized, if this is necessary, when the wound is disinfected and when all possible extension of the soft parts has been obtained.

A study of the end results justifies the conclusion that the flapless type of amputation had a definite place in military surgery. It possessed the advantages of preserving the maximum length of stump, of providing wide drainage and of requiring a minimum of time for its performance. It had the disadvantages of requiring a protracted period of after-treatment and of necessitating in most instances secondary reconstruction operations to prepare the stump for prosthesis. Cases operated by this method at the front usually were kept under observation for 48 hours, at the end of which time they could be evacuated in safety. If necessary they could be evacuated immediately with only slight risk. Their after-treatment was exclusively a matter for the base hospitals to which they had been evacuated.

IN THE BASE HOSPITALS

Nearly as many amputations were performed in the base hospitals at the rear as in the evacuation hospitals at the front. The great majority of these amputations were performed for sepsis and were of the open or flapless type.

The procedure here was similar to that of the front, but with the difference that the patient who was usually very ill did not have to be evacuated. The after-treatment was under the control of the surgeon who performed the operation.

In the case of infection involving the upper end of the tibia or the knee joint, disarticulation of the knee by the flapless method proved a useful procedure. The operative risk was much less than with amputation of the thigh and it also possessed the advantages of opening up a smaller amount of fresh tissue to infection and of not giving rise to troublesome retraction of the soft parts. Later, when disinfection was obtained, reamputation for the purpose of regularizing the stump could be performed under ideal conditions.

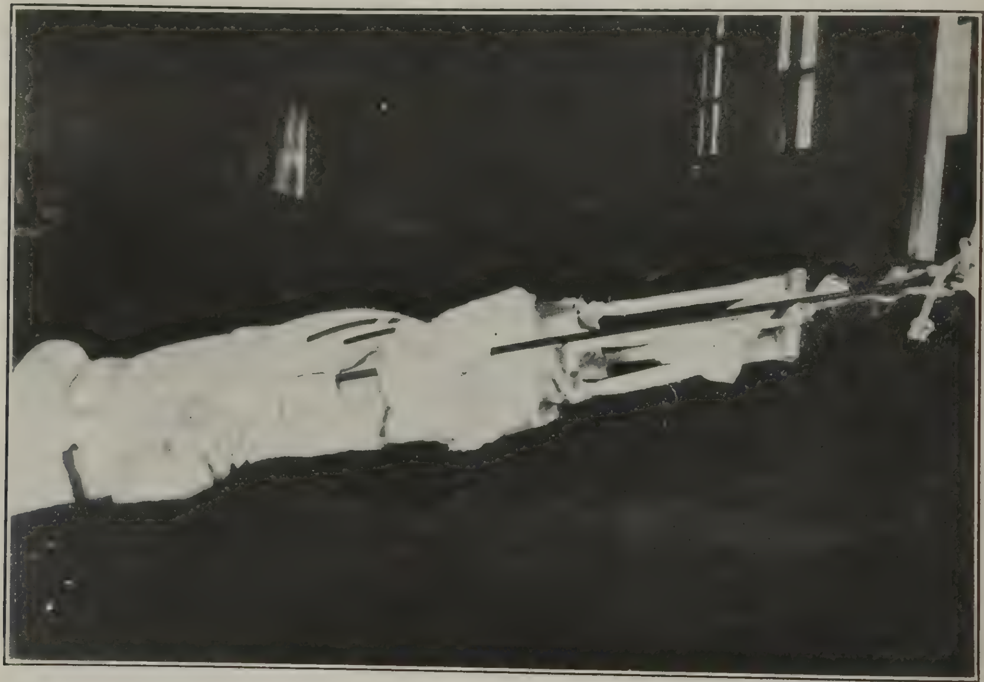

FIG. 129.—Use of Thomas splint in application of fixed extension to an amputation stump to overcome soft part retraction

A good many amputations were necessitated by secondary hemorrhage. Such hemorrhage was always caused by burrowing sepsis, and it was in order to control the latter rather than to stop the hemorrhage that amputation was indicated in most instances. In a certain number of cases amputations were performed, not for sepsis alone, but because of the presence of hopelessly mutilating injuries or of chronic sepsis in which it was apparent that a better functional result would be obtained with an artificial limb than with the injured member even if the treatment of the latter should prove unexpectedly successful. In practically all amputations of this latter group the part involved was the foot, ankle, or lower leg. It was well recognized that the possibility of saving any part of a hand justified a long uphill fight, whereas, with the leg, the functional result with an artificial limb was in many cases better than if a badly damaged foot or ankle had been preserved.

Treatment Immediately Following Amputation

The chief problem of after-treatment was the large number of open amputation wounds. Very little difficulty was experienced in the case of amputations treated by either primary or delayed closure. Unfortunately, the number of these, from the nature of the military situation, was extremely small. This is shown by the following figures obtained from a group of 550 cases treated at the Hospital Center, Savenay.[2] Of these, 323, or 58 per cent, were either flapless or guillotine amputations; 170, or 30 per cent, were amputations with flaps but without closure, and only 62, or 11 per cent, were amputations with closure. Of the 550 cases, 493, or 88 per cent, were open amputations as against 11 per cent closed. It is also interesting to note that of the 62 cases with primary or delayed primary suture, only 75 per cent remained closed.

Fig. 130.—Use of a spreader in sliding extension applied to an amputation stump to overcome soft part retraction

Soft-Part Retraction

With an open stump, the chief danger in respect to future function was that of retraction due to the contraction of the severed muscles. Thus, in an amputation of the thigh by the flapless method, if the stump was examined a few days after operation it would be found that the skin had retracted considerably above the level of the bone and that the surface of the wound instead of remaining a plane had become frankly conical. If the process was allowed to continue, at the end of two to three weeks the end of the stump would have

become a long tapering cone with the bone protruding a distance of 2 to 3 inches, and the distance between the bone tip and the retracted skin margin 5 to 6 inches. If nature was permitted to pursue her course, the marginal cicatrix contracted, shutting off the blood supply to the distal part, and after 8 to 10 weeks there remained only a protruding length of bare bone which in the course of time was sloughed away.

FIG. 131.—This and Figures 132 and 133 show amputation of the thigh by the flapless method in various stages of healing under the influence of continuous extension. In this figure, the first stage, all possible extension of the skin flaps has been obtained with the result that the skin has turned in over the end of the stump

The process of retraction and natural reamputation was seen in its most extreme degree in the thigh but it could also be observed in amputations of the upper arm, forearm, or lower leg. It always led to a considerable diminution in the length of the stump, and in the case of the thigh this often amounted to as much as 5 or 6 inches. In addition it rendered the stump conical and less suitable for prosthesis while at the same time decreasing its power. Usually a broad, thin terminal scar resulted which was adherent to the bone, and a secondary operation usually was required before an artificial limb could be worn. But a stump is, above all things, a lever and, except in certain special regions which are mentioned elsewhere, its most important asset is length. Therefore the importance of counteracting this process at its inception was obvious.

FIG. 132.—Second stage. The scar is contracting, but a fairly large open area with indolent skin margin remains

Soft-part retraction could be prevented or, if already present, could be overcome in large part by the proper use of extension. Extension was obtained by the application to the skin of adhesive plaster strips which extended from as close to the skin margin as possible, well up to the base of the stump. The free ends of the strips were attached to tapes and these were fixed by buckles to a spreader of suitable size and shape to which the extension cord was fixed. Traction was obtained either by leading the cord over a pulley at the end of the

bed and fastening it to a weight (sliding extension), or by applying a short Thomas splint and the cord fastened to its end under tension (fixed extension). Sliding extension usually was best for hospital treatment, but the fixed extension with the Thomas splint was required for transportation. The adhesive strips did not interfere with the application of the dressings, and the strips were unbuckled from the spreader when complete exposure of the wound was required. The wound treatment could be carried on as adequately with the extension as without.

FIG. 133.—The end result which may be expected in the absence of bone infection. The scar has shut down, pulling the skin with it, and there now remains a thin, adherent puckered scar

Under the influence of extension retraction was prevented and healing proceeded rapidly. With the circular, flapless type of amputation, the end result was a thin round cicatrix at the end of the stump with or without sinuses, depending upon the degree of bone infection. In open amputations with short flaps the result was often a linear scar, and such stumps were quite suitable for prosthesis without other intervention. The great majority of the open amputations, even when treated with extension, required secondary operations to get rid of the scar and the infected tip of bone. Most of these operations were of a simple nature, however, and did not constitute formal reamputations.

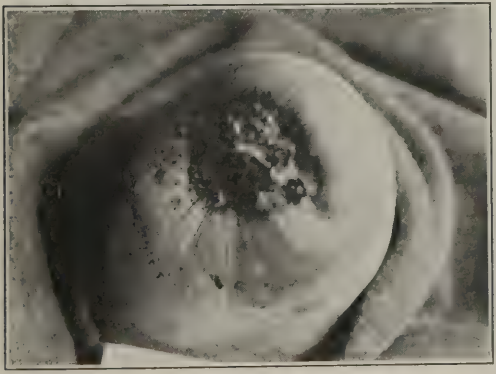

FIG. 134.—Amputation of the thigh by the flapless method with oblique section in order to save the maximum amount of soft tissues. The stump has healed under extension, but there remains a chronic osteomyelitis with multiple sinuses

SEPSIS

Septic stumps constituted an important part of the amputation problem. Infection was usually only the continuation of the process for which the amputation itself had been performed. It is safe to say that all open amputations were infected. All types and degrees of infection were seen and all of the possible septic complications were encountered at different times. Such complications were treated according to the usual surgical principles and require no special mention. In respect to the special manifestations of infection as seen in amputation stumps the most important feature noted was the little difficulty experienced with the flapless type of amputation and the endless trouble encountered when a partial closure had been attempted or when flaps had been formed which tended to fall together.

Many of the infections terminated by the formation in the stumps of residual abscesses which required drainage; occasionally the infection extended to the neighboring joint with the production of a septic arthritis. In a below-the-knee amputation, with secondary infection of the knee joint, if the septic arthritis

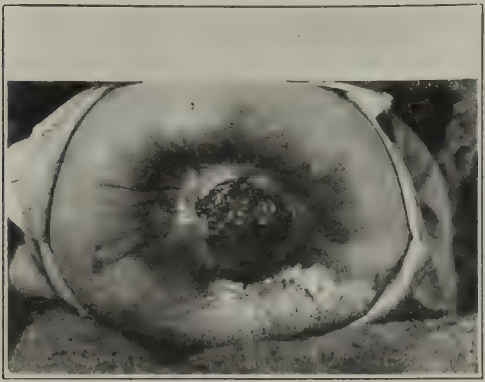

Fig. 135.—Short amputation of the thigh. There has been considerable retraction of soft parts, but the stump has been treated by extension, with considerable gain

Fig. 136.—Short amputation of the thigh, with marked retraction of the soft parts and protrusion of the end of the bone covered by granulation tissue

did not respond rapidly to drainage, the chance of procuring a useful joint was not great enough to justify a protracted fight, consequently reamputation above the knee was resorted to much earlier than if there had been a normal limb.

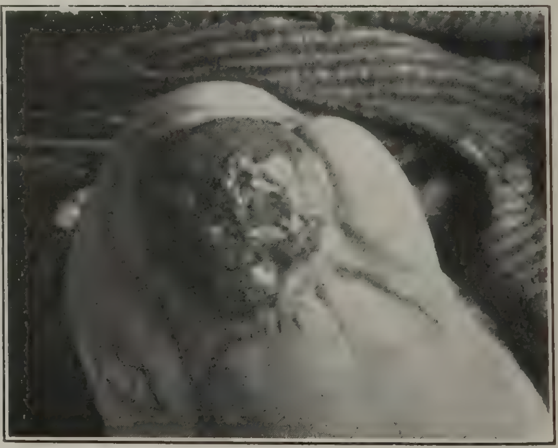

Fig. 137.—This and Figure 138 show plastic closure of an open amputation stump, with marked retraction of the soft parts. In this figure the retraction of the skin margins is noticeable, and there are bad scars

The best method of treating wound infection in an amputation stump was found to be the Carrel-Dakin method. Most of the wounds responded well to this treatment; some were disinfected entirely and in them secondary suture was successfully performed. A troublesome feature with the Carrel-Dakin method in amputation wounds was the tendency for the Carrel tubes to become displaced. This was obviated by stitching them, at intervals of about 1 inch, to a piece of gauze and applying the pad with its attached tubes to the wound. These batteries of tubes were made up beforehand, sterilized, and kept ready for use. For the thigh about eight tubes were required, for the arm or lower leg, about four. They could be used quite readily even when the stump was being treated with extension; thus effective contact of the solution with all parts of the wound was assured.

After the acute infection had cleared up, a focus of chronic osteomyelitis in the terminal portion of the severed bone usually remained. Almost invariably multiple short sinuses existed, and as long as these remained open no difficulty was experienced. Wound healing progressed satisfactorily in such cases until only a central ulcer remained, then the sinuses would begin to close, the discharge would back up, and abscesses form. At this stage it was necessary either to remove the sequestrum, if this could be found, or to excise the terminal portion of the bone. It was always better to perform these operations in separate steps, preliminary to the later reconstructive operation, rather than to

FIG. 138.—The same stump as that shown in Figure 137, after closure. The wound was excised, with a cone of tissue and the tip of the bone. The skin flaps were mobilized and drawn together

FIG. 139.—Double amputation of both legs. The flapless method has been used in the right and there is an extensive terminal osteomyelitis

attempt to combine the two in one sitting. In the combined operation the wound almost invariably became infected, causing its breakdown and a repeated operation.

Hemorrhage

Secondary hemorrhage was an infrequent complication of amputation, this experience being in marked contrast to that of the Civil War.[7] Hemorrhages occurring 24 to 48 hours after amputation were due generally to an improperly placed ligature, or to one insecurely tied. Subsequent to this time it was usually the result of sepsis. Hemorrhage was a rare complication of the flapless type of amputation, even when the stump was badly infected, but was encountered more frequently in the amputation with flaps, loosely sutured, in which drainage was not so adequate.

Joint Deformity

Limitation of movement in the proximal joint of the stump was another complication to be feared in amputation cases. When it occurred limitation of movement was usually the result of fixation of the stump for a considerable period in improper position. The patient with a sensitive amputation stump always tried to get it into a position of muscular relaxation and to avoid movement. After a time adaptive shortening of the muscles occurred, the capsule contracted, and limitation of movement resulted. This tendency to contracture was increased still further by the presence of infection and periarticular inflammation. Generally joint deformity was found when treatment had been neglected, and in the case of a thigh amputation was furthered by the baneful practice of propping the stump in flexion on a cushion. It was more apt to develop in short stumps where its presence was most harmful. The usual deformities were: In amputation of the lower leg, incomplete extension of the knee; in amputation of the thigh, flexion of the hip; in amputation of the forearm, flexion of the elbow and limited rotary movement of the forearm; in amputation of the upper arm, adduction of the shoulder. The movements impaired were precisely those which are most essential in order to obtain the best function with a prosthetic appliance. Moreover, such joint deformities, in most instances, were avoidable. When splinting was indicated it was necessary only to fix the joint in the optimum position and to require that the joint be moved through its normal range of motion a few times each day. Continuous extension, in addition to preventing retraction, was also an excellent method of preventing joint contractures. With amputations of the lower leg and thigh it maintained the knee and hip in the extended position, and in the case of the upper arm it was applied usually in such a way as to hold the shoulder abducted, these positions being, in each case, the best for the recovery of function.

TERMINAL CONDITIONS

As outlined above, such were the chief problems of treatment in the period immediately following amputation; however, many conditions were encountered which constituted the problems of the more remote periods of treatment. These were the so-called terminal conditions.

At no time was it the policy of the division of orthopedic surgery, A. E. F., to undertake reconstructive surgery in France unless thereby the patient could be restored to duty. In amputations the main object was to conserve function in every possible way and to prepare the patient for evacuation to the United States. However, the matter of so evacuating the wounded proved a very uncertain thing, especially for recumbent cases. Delays were numerous. In the principal evacuating centers, such as the hospital center at Savenay, there were always on hand ready for evacuation several times as many patients as could be accommodated in the convoys. While awaiting transportation many of the amputation cases went on to the terminal stage of convalescence, and in certain instances advantage was taken of this delay to perform secondary reconstructive operations. These were done chiefly in an effort either to render the long sea trip a safer procedure than it otherwise would have been or to shorten the period of convalescence.

Among the conditions thus treated were: Protruding bone; localized terminal osteomyelitis; terminal ulcers; painful neuromata; painful osteophytes; intractable joint deformities; stumps unsuitable for prothesis, either by reason of amputation at an unfavorable level or because of insufficient covering of soft parts.

Protruding Bone

Amputation cases were encountered with a variable length of bare bone protruding from an otherwise fairly well-healed wound. This condition, as noted above, was mainly the result of failure to employ extension and of consequent soft part retraction. Occasionally it was due to the hurried amputation of an infected compound fracture where the soft parts had been simply divided near the seat of fracture without rectification of the bone. It was always deemed advisable in such cases to remove the protruding bone by sectioning it at a level below the soft parts without disturbing the rest of the wound. The incision was left open, the cavity rapidly filled in with granulation tissue, and complete cicatrization was usually obtained. Thus the patient was made ambulatory and provisional prosthesis could be applied.

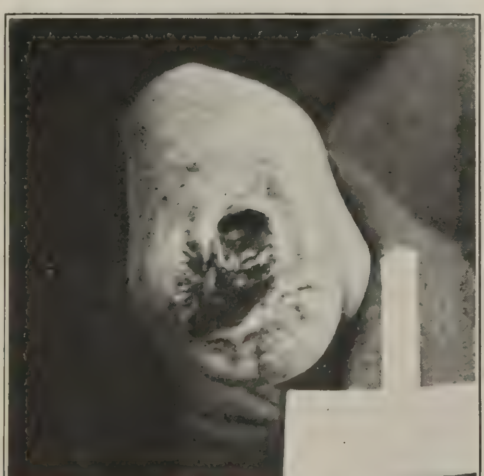

Fig. 140.—Short amputation of the lower leg, with marked flexion contracture of the knee. Open wound, with chronic osteomyelitis

Localized Terminal Osteomyelitis

As stated above, terminal localized osteomyelitis was the usual end result in infected amputation stumps. When such cases had progressed to the chronic stage it was necessary to get rid of the septic focus. In some, sequestrectomy was sufficient; in others, the infected part had to be excised. These operations, in the majority of instances, were of a simple nature and were done

to allow the stump to become aseptic, so that the necessary reconstructive operations, which would be required later, might be performed under the most favorable conditions.

Terminal Ulcers

A common result in the flapless type of amputation was an indolent ulcer, situated in the center of the scar, directly over the end of the bone. This was caused practically always by cicatricial interference with the blood supply to the central part of the wound. In such cases complete healing could not be obtained. The end of the bone was in close relation to the base of the ulcer and there was frequently an associated osteomyelitis. To close such a stump it was necessary to excise the scar with the tip of the bone and perform a plastic skin operation. If the stump was short and the amputation situated at the so-called critical level, it was sometimes advisable to transplant a pedicle skin flap from the opposite limb in a two-step procedure.

Some of these operations were performed in the American Expeditionary Forces, but usually only because of exceptional circumstances. There was a considerable hazard in respect to the results on account of the danger of stirring up a latent infection, and if all did not go well, evacuation might be considerably delayed. On the other hand, these cases were ambulatory and could be evacuated in safety, without operation. Treatment, therefore, was usually deferred until arrival in the United States.

Painful Neuromata

Many stumps were painful, but in only a few were the symptoms due to neuromata. In the majority the causes were to be found either in infection and its sequelæ or in circulatory disturbances. When definite evidence indicated a neuroma as the cause of the symptoms it was always sought to relieve the condition by operation. Such procedures were simple, gave immediate relief, and did not delay evacuation.

Painful Osteophytes

Painful osteophytes constituted a very minor part of the amputation problem in the American Expeditionary Forces, although bony spurs were present in many of the cases, sometimes in extreme osteophytes. Much remains to be learned concerning the cause of these osteophytes. In many of the war cases infection undoubtedly played an important rôle in their production, but they were also encountered in clean cases. Certain of these were probably caused by unnecessary fraying and shredding of the periosteum at the time of amputation. They might have been avoided in many instances if the aperiosteal method of sectioning the bone, advocated by Bunge,[7] could have been employed more widely. This procedure, however, was not advisable in potentially infected cases such as these. When it was used and infection developed, separation of a ring-like sequestrum from the end of the bone resulted.

Fortunately, osteophytes rarely caused trouble if the stumps were satisfactory in other respects. Occasionally a very large spur was found which seemed likely to interfere mechanically with the application of a prosthetic appliance, and in such a case it was usually excised.

Intractable Joint Deformities

Correction of joint deformity, when present, was considered a very necessary therapeutic measure before evacuation of the patient to the United States. The majority of such deformities yielded to massage and exercise. Intractable deformities were occasionally encountered; they occurred most commonly in short amputations of the lower leg and thigh. The application of provisional prosthetic appliances, when this was possible, with the active

Fig. 141.—This and Figure 142 show the provisional appliance used in the American Expeditionary Forces for above-the-knee amputation. Lateral view with the peg flexed. The frame can be adjusted to the length of the stump

voluntary movement which their use stimulated, proved the most valuable single measure in counteracting these contractures. Unfortunately there were some very bad deformities in which prosthetic appliances could not be used, either on account of the presence in the stump of open wounds or because the amputation was associated with an injury to another part of the body which necessitated recumbent treatment. In such cases the best treatment was either continuous extension or corrective splinting.

Stumps Unsuitable for Prosthesis

Many healed amputation stumps were unsuitable for prosthesis, either by reason of amputation at an unfavorable level or because of insufficient covering of soft parts. Such cases usually required formal reamputation. It was against the general policy to perform these operations in the American Expeditionary Forces as they needlessly delayed evacuation to the United States. Occasionally, when considerable delay in evacuation obtained, and

FIG. 142.—Front view. The peg is extended and locked

when there was assurance of being able to perform the reamputation cleanly, these operations were done, but in general they were deferred until after arrival in the hospitals at home.

Provisional Prosthesis

The pioneer work of Martin [8] and of Hendricks, both of the Belgian Medical Corps, in the early years of the war had demonstrated in striking

manner the beneficial effects of early weight bearing in the treatment of amputations of the lower limb. It was considered highly desirable to utilize this principle to as large an extent as possible in treating the amputation cases of the American Expeditionary Forces. Prosthetic appliances of suitable design for amputations of the lower leg and thigh and of sufficient simplicity to lend themselves to the purpose were therefore worked out and arrangements for their manufacture made with the American Red Cross in France.[9]

FIG. 143.—Type of temporary appliance used for hip-joint amputations

The appliance for thigh amputation consisted of a light steel frame to hold the socket which in the region of the knee was joined to a wooden block. This supported a strong wooden peg with rubber tip by which the weight was transmitted to the ground. There was a joint mechanism at the knee with lock, by means of which the peg could be flexed when sitting and locked in extension when standing. The appliance for amputation of the lower leg consisted of a light steel frame which terminated below in a simple type of articulated wooden foot. It was equipped with a laced leather corset for the thigh which was joined to the leg portion by steel side pieces, jointed at the knee. The sockets, in every instance, were of plaster of Paris, modeled directly to the patient's stump. The prosthetic appliance was fixed to the socket by a few turns of plaster bandage. The same bearing points were utilized as in the case of the permanent artificial limbs. These were chiefly the bony prominences, the tuberosity of the ischium for thigh amputations and

the shelving under surface of the upper end of the tibia for amputations of the lower leg. Secondarily the weight was taken by the soft parts, but always in a manner to relieve the wound of pressure, the lower end of the socket being left open for this purpose.

With temporary legs of this type it was possible to get patients out of bed and walking without other support very shortly after amputation. In

FIG. 144.—Patients with above-the-knee amputation fitted with the temporary peg leg with plaster socket

the case of clean sutured stumps weight bearing could be begun in two to three weeks. With open stumps it was necessary to wait considerably longer, until healing had progressed to a point where only a small wound remained. In such cases it was necessary to take steps to prevent the soft parts from being pushed upward by the pressure of the socket, a condition which might cause separation of the flaps in a recently healed stump, or retraction of the soft parts and protrusion of the bone in a stump with an open wound. Pro-

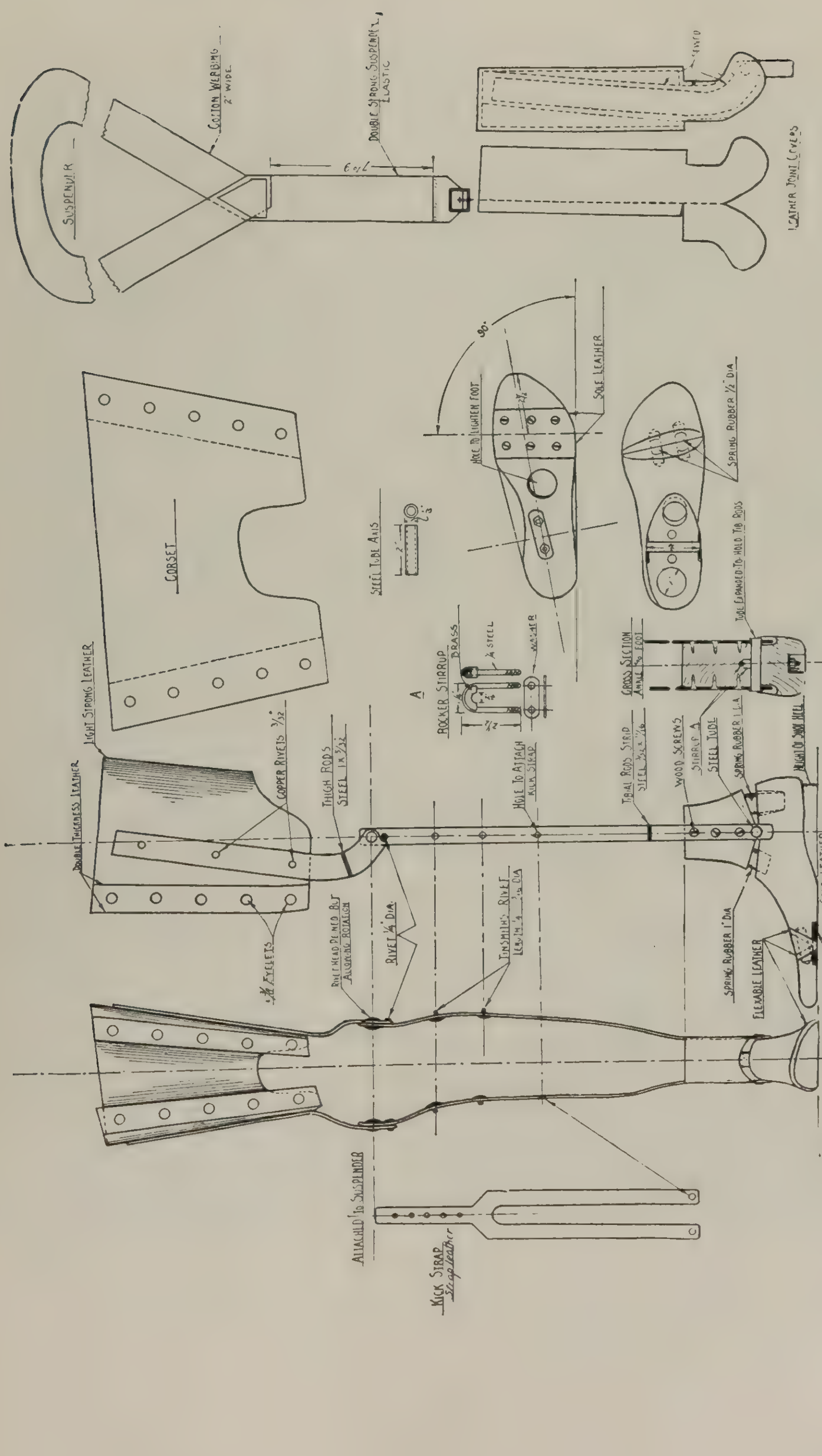

FIG. 145.—Mechanical drawing of the provisional appliance for below-the-knee amputation used in the American Expeditionary Forces

FIG. 146.—Application of the provisional appliance for below-the-leg amputation. The skeleton leg is fitted to the stump and the side irons are bent to conform to its shape

tection was always provided in such cases by the application of traction. Broad adhesive strips with tapes were applied to the skin surface above the wound and the tapes passed down through the open end of the socket and fastened under tension to the lower portion of the apparatus. These traction strips served also to fix the leg to the stump and were used sometimes in lieu of suspenders.

While it was realized from the beginning that the percentage of amputation cases in the American Expeditionary Forces to whom this method of treatment could be adapted would be small, it was felt that the advantages

FIG. 147.—Application of the provisional appliance for below-the-leg amputation. The stump is covered with stockinette and the end protected with a cardboard cuff

to be obtained from it when it could be used would be so definite as to more than justify the effort. The results achieved more than sustained this prediction. Legs were applied in about 500 cases or in approximately 20 per cent of all amputations of the lower extremity.[10] Early weight bearing was shown to be of benefit in several different ways. It promoted wound healing by improving the circulation, and in cases with terminal localized osteomyelitis it favored the separation and spontaneous discharge of sequestra. It hastened stump shrinkage and prevented muscle atrophy and the development of joint contractures. In this respect it was far more valuable than any form of

FIG. 148.—Application of the provisional appliance for below-the-leg amputation. Two plaster bandages are applied and modeled carefully to the contour of the stump to form the socket

FIG. 149.—Application of the provisional appliance for below-the-leg amputation. The provisional appliance is then applied, the joint centered carefully in relation to the knee, and the frame incorporated in the plaster socket by additional turns of plaster bandage

physiotherapy. It had an important psychological effect in counteracting despondency and in improving the patient's morale. In the healed cases it

FIG. 150.—Application of the provisional appliance for below-the-leg amputation. The upper margin of the socket is carefully lined with pencil, passing front just below the patella and being hollowed out behind to allow flextion of the knee

greatly reduced the intervening time until the permanent artificial limb could be fitted, and thus shortened the period of convalescence.

FIG. 151.—The temporary leg completed, ready to apply

FIG. 152.—Group of soldiers fitted with temporary peg legs. These were the appliances used before the development of the articulated foot appliance

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CHAPTER VII

CARE OF THE AMPUTATED IN THE UNITED STATES

ADMINISTRATION

The experience of the European nations at the time of our entrance into the conflict was already sufficient to indicate clearly the possible magnitude of our amputation problem. The general use of high-explosive shells and the prevalence of gas gangrene had increased greatly the frequency of amputation and had counteracted the gain due to improved surgical methods; so that, in the face of an estimated total at that time for all the countries engaged of nearly 300,000 amputations, the artificial limb problem had naturally become a serious economic question abroad. While our own country was particularly fortunate in possessing a thriving artificial-limb industry, its usefulness was in great danger of being seriously curtailed both through the loss of its skilled workmen in the draft or by transfer to munition work and also through difficulty in securing supplies. It seemed wise, therefore, for our country to make provision for meeting the greatest possible demand under the most unfavorable conditions.

It is evident that the highest degree of functional use with the artificial limb can be assured only through an organization of the work which takes into account every phase of treatment. Hence provision must be made for systematic attention during each of the five stages into which treatment naturally divides itself: (1) The amputation itself; (2) the care of the stump; (3) provision of the artificial limb; (4) general functional training; (5) special vocational training. During these successive periods the amputated pass under the care of the surgeon, the artificial-limb maker, and the educational officer. Furthermore, success in training depends in no small degree on the attitude of the general public. To secure the effective cooperation of all these agencies called for a definite program of education.

EDUCATIONAL PROGRAM

On the part of the surgeon, considerable uncertainty still existed as to the preferable sites of amputation, little attention had been paid to systematic stump care, the use of temporary appliances with plaster-of-Paris sockets as a means of securing early functional use of the stump was practically untried in this country, and but little was known of the general principles of prosthesis. Moreover, the circular method of amputation, which had been found so necessary and advantageous in counteracting the dangers of infection, required an entirely different character of after-treatment from the customary amputation of civil life. All these points were covered in articles relating to amputations, fitting artificial limbs, and the care of the stump,[1] and were distributed in reprint or other forms to Army surgeons. Further instruction in the subject was given to student officers by means of didactic and clinical lectures and practical demonstrations in the various courses of instruction in military

orthopedic surgery. In these courses the artificial-limb makers were frequently called upon to explain the design and construction of artificial limbs and the principles of fitting. Later, as the amputation center at Walter Reed General Hospital developed, medical officers were sent there for courses of instruction in the care of the stump, the principles of stump surgery, the technique of the construction of the temporary peg legs, and the general principles of artificial limbs.

To educational officers and reconstruction aides, talks, supplemented by the use of moving pictures, were given, covering particularly the details of the later stages of treatment.

For the amputated themselves this general educational work consisted of talks to all the men by those in charge of the service, and also practical demonstrations in which civilian amputated who had acquired especial skill showed what is possible with and without an appliance. Facts which every amputated individual should know were formulated and issued in pamphlet form.[2] To this was added later information concerning obtaining permanent artificial limbs.[3]

The slight degree of incapacity for most occupations caused by the loss of a leg, provided a proper appliance be worn, was a matter of common knowledge on the part of the general public in our country, but the possibilities in loss of the upper extremity were not so generally known. Moreover, with rare exceptions, employers were prejudiced against the hiring of such men for manual occupations. It was imperative, therefore, that the public should be taught to what extent and in what occupations the amputated were able to carry on productive labor. The success of this part of the work, which was taken over by the division of physical reconstruction, Surgeon General's Office, as a part of its general campaign of education,[4] was made possible largely through the generous assistance rendered by the many amputated men throughout the country who had attained positions of competence.

AMPUTATION CENTER

In planning for hospital accommodations, consideration of efficiency and economy indicated the desirability of segregating the amputated, as far as possible, in one center preferably reserved exclusively for such cases. This was in accord, too, with the experience of other countries. With such a unification of the work, the fitting of appliances would be greatly facilitated, training in all its forms more readily carried out, and the study of the various problems in the care of this type of case carried on under the most favorable conditions. Unfortunately, the size of our country offered too great an objection to this arrangement, since the distances involved in the majority of cases were so great as to make it impracticable for the returned soldier to be furloughed to his home or to be visited by his friends. The situation seemed to be best met, therefore, by arranging for a chief amputation center, near the ports of debarkation, with a limited number of subcenters in other parts of the country.[5]

Walter Reed General Hospital, Washington, was accordingly chosen by the Surgeon General as the chief amputation center, and Letterman General Hospital, San Francisco, General Hospital No. 26, Fort Des Moines, Iowa, and General Hospital, Fort McPherson, Ga., were designated as subcenters.

A little later, United States Army General Hospitals No. 29, Fort Snelling, Minn., No. 3 at Colonia, N. J., and No. 10, at Boston, were also designated as subcenters. Early in 1919, a change was made in this arrangement, No. 3 at Colonia being designated as the distributing center for all cases of amputation arriving at the port of New York [5] and Walter Reed General Hospital for all those arriving at Newport News.[5] Since the port at New York was the one finally used, this resulted in making these services practically equal, each maintaining an average of between 600 and 700 cases during the late spring of 1919. The center at Fort Des Moines became third in importance. That at Letterman General Hospital proved to be the smallest in point of numbers, but it maintained a very high standard of work.

THE HOSPITAL SERVICE

The ward organization of a large amputation service proved to be an important factor in its success. It was found that not only could treatment be carried out more easily but that discipline was more readily enforced when the cases were divided according to the stage of treatment. A division into the following groups proved the best arrangement: The unhealed; the preoperative and postoperative; the prefitting and postfitting; the training groups. In the unhealed group, the further separation, as far as possible, of the recumbent and ambulatory cases aided materially in the control of those who were recumbent.

An appliance shop for artificial-limb fitting was provided at each center except at Fort Snelling; here it seemed more expedient, owing to the proximity of one of the manufacturers of the provisional appliances, to have the fitting done at the factory. In arranging the shop facilities, it was not found necessary to install an extensive equipment, since parts whose construction called for unusual or expensive machinery could easily be secured from regular artificial-limb manufacturers. This greatly simplified the problem, the equipment thus required being no more than that needed for the ordinary orthopedic brace work. Considerable floor space was necessary, however, in order to take care of a large number of cases easily and rapidly; one of the regular one-story pavilions met the needs very well in the smaller centers while in the larger, one of the regular reconstruction shops proved most satisfactory.

The medical personnel of the amputation service consisted of its chief who had also professional supervision over the shop, one or, in the larger centers, usually two assistants, one or sometimes two officers in charge of the shop, and the usual number of ward surgeons. The assignment of an additional officer to both the postfitting wards and the shop was found most helpful in securing better supervision and fitting.

The task of securing the required skilled personnel, for surgical and for prosthetic work, proved more difficult than was anticipated. Lack of training in the care of the amputated was largely responsible for this in the case of the surgical personnel, but it was due also to the qualifications demanded by the work, a considerable mechanical ability in addition to the surgical knowledge being necessary. Furthermore, few men were anxious to confine themselves to such an apparently restricted field for the duration of the war. In the case of the personnel for prosthetic work, the artificial limb workmen accepted

under the draft were few in number and on account of their age naturally of only moderate experience. Moreover, owing to the regulations covering overseas duty, it was difficult or even impossible to reserve them for domestic service. The number secured was so small that it became necessary to train men for the various details of limb construction and fitting.

ARTIFICIAL LIMB LABORATORY

The Surgeon General recognized from the first the importance of making adequate provision for the study of the design and construction of prostheses, particularly from the standpoint of standardization, and for the proper testing of the many new appliances and devices which were being constantly presented, as well as for the carrying out of experimental work. He accordingly authorized the establishment of an artificial limb laboratory for this purpose.[6] The equipment for this laboratory, which it seemed wisest at first to restrict to a comparatively simple character, was installed at the Army Medical School, Washington, D. C., in January, 1918,[7] but was moved to the Walter Reed General Hospital in March of the same year,[7] in order to secure better coordination between the experimental and the clinical parts of the work. A certain amount of both experimental and routine prosthetic work was still carried on at the Army Medical School, however, throughout the war, in the shop of the orthopedic section.

SUPPLY OF ARTIFICIAL LIMBS

The artificial-limb situation in the United States was such as to put on the question of Government manufacture an entirely different aspect from that which obtained in other countries. The large number of amputations in the Civil War, with the enormous yearly addition from industrial accidents which occurred before the introduction of the "Safety first" movement, had tremendously stimulated endeavor in this field, so that our artificial-limb industry had become the best developed in the world. Not only was the industry a large and thriving one but in addition it was well distributed geographically, so that there was hardly a city of importance that did not have one or more artificial-limb concerns. While the output of some of these was small and the shop facilities far from modern, a number of our larger firms had been engaged since early in the World War in supplying limbs in very considerable numbers to our Allies, thus showing their ability to handle a large volume of business. Also it was learned by means of a questionnaire sent out by the Surgeon General that the industry as a whole, with its existing equipment, could produce a thousand limbs per month in addition to the number required for civilian needs.[8] Furthermore, in order to be better prepared to handle the problem and to utilize to the fullest extent the resources of our country in this respect, the manufacturers, at the suggestion of the Council of National Defense, had formed The Association of the Artificial Limb Makers of the United States.[9] In view of the ample facilities afforded by the established industry, therefore, it seemed unnecessary to attempt Government manufacture.

Our relation to the question of standardization also seemed to differ from that of other countries. Examination of the product of a large number of concerns showed a surprising uniformity in all essential points. While differing

in minor details, they were with few exceptions similar in design, substantial in construction, and excellent in workmanship. Since the established policy of bonding manufactures who desired to supply limbs to the Government furnished a means of eliminating the incompetent, it seemed unwise during the stress of war to subject approved manufacturers to the expense and inconvenience that would be caused by the insistence on the production of definitely standardized types. Moreover, while the needs of the Army might have been met in a very satisfactory manner by the arbitrary choice of any one of several established models as a standard, an actual standardization was clearly out of the question at that time. To be of any real value standardization can not be based on opinion but must rest on scientific study. It is an undertaking which is obviously not to be considered during war but which offers a very proper subject for the attention of the Government in times of peace.

Our artificial-limb problem was made somewhat more difficult by the enactment of the War Risk Act, October 6, 1917.[10] Up to this time artificial limbs had been issued by the Medical Department, and hence under the authority of the War Department. In this act, however, Congress provided for their issue to discharged soldiers and sailors through the Bureau of War Risk Insurance, thus transferring the authority to the Treasury Department. The situation was thus complicated in that the case passed from the control of one branch of the Government to that of another at an important stage in treatment. For, to retain the amputated soldier in the service as a patient in an Army hospital during the long period necessary for the stump to attain its final form and so be in proper condition for the fitting of the permanent artificial limb, was obviously inadvisable from the standpoint of the Army and of the soldier himself. Yet it was just as obviously essential to provide for his proper training in the use of an appliance of the final type, such training being regarded as one of the most important parts of modern treatment.

To meet all these conditions the provision of prostheses of regular design, so as to fulfill the requirements of training, but constructed with the intention of meeting the demands of the wearer only during the first six months, or if necessary the first year, of stump life seemed most satisfactory. An artificial leg of this sort can be constructed on the "ready-made" plan. Fiber may be used in place of wood and sufficient parts carried in stock to fit individuals of different height and size of stump. The fiber socket can be adapted very satisfactorily to thigh amputations, while in below-knee amputations it can be used to hold the plaster-of-Paris socket. The artificial arm can be constructed on this plan more easily than the artificial leg. The advantages of such a method are many: (*a*) The minimum demand is made upon industry, since all the work of manufacture may be done in established plants and only such shop facilities have to be provided at the amputation center as are required for fitting and repairs. (*b*) Production in any quantity is possible, and hence in the event of the number of the amputated being so great as to overtax the established artificial-limb industry, a means is thus provided for meeting the need until such time as the permanent limb can be secured. (*c*) The maximum number of amputated can be cared for, the time required for fitting the ready-made appliance being much less than for the special one, and no more than

when the temporary leg is used. (*d*) The educational value of the provisional leg is an important feature, the wearer learning how an artificial leg should feel and act and how to care for it; this knowledge naturally makes easier the work of the skilled artificial-limb maker and is at the same time the most certain means at our command for eliminating the unskilled one. (*e*) The conditions imposed by the War Risk Act are met most satisfactorily. (*f*) An equitable distribution of the work of supplying the permanent appliance is favored, since it is not secured until the amputated have reached their homes; this not only makes possible the maximum output but is in accord with established Government policy.

TREATMENT OF AMPUTATION STUMPS

In order to record fully the results of experimental development and clinical observations of the surgical and prosthetic treatment of stumps in all centers, a questionnaire was prepared covering all the salient points. This was submitted to the former chiefs of amputation centers with a request that a detailed statement of their observations and experiences be given, using the outline as submitted in order to facilitate the study of comparative methods and results. The experiences herein related and the conclusions drawn constitute a review of the reports received from the former chiefs of amputation sections.[11]

AMPUTATION CASES RETURNED TO THE UNITED STATES

The following is a list of the total number of amputation cases which were returned to the United States:[12]

LOSS OF EXTREMITIES

Upper extremity:	
One arm above elbow	550
One arm at elbow	41
Both forearms	3
One forearm	212
One hand at wrist	26
Both hands	1
One hand	18
Part of both hands	4
Part of one hand	1, 481
One arm and one forearm	1
One arm above elbow and part of hand	4
One arm below elbow and part of hand	1
One forearm and one hand	2
One hand and part of hand	2
Total	2, 346
Lower extremity:	
Both thighs	11
One thigh	1, 137
Both legs at knee	1
One leg at knee	95
Both legs below knee	9
One leg below knee	327
Both legs at ankle	3
One leg at ankle	131
Both feet	1
One foot	20

Lower extremity—Continued.	
Part of both feet	3
Part of one foot	280
Thigh and leg at knee	2
Thigh and leg below knee	5
Leg at knee and part of foot	2
Leg below knee and foot	2
Leg below knee and part of foot	3
Total	2, 032
Upper and lower extremities:	
Arm above elbow and one thigh	3
Arm above elbow and leg below knee	1
Arm above elbow and one foot	1
Arm above elbow and part of one foot	1
Arm below elbow and one thigh	2
Arm below elbow and leg below knee	4
One hip and part of hand	1
Leg at thigh and part of hand	8
Leg at knee and part of hand	1
Leg below knee and part of hand	3
Total	25
Grand total	4, 403

CONDITION OF STUMPS ON ARRIVAL IN THE UNITED STATES

In 1918, when the number of amputations was yet small, the majority of stumps were healed when they were received in base hospitals in this country,

FIG. 153.—This and Figures 154 to 157 show the average sagittal stumps from four to eight months after trauma

FIG. 154

and many of them were fitted with temporary appliances. Later, when the number of wounded rapidly increased, most of them were only partially healed. Contractures of adjacent joints were only occasionally seen, the most common

being short thigh stumps showing a varying degree of flexion and abduction deformity; flexion contracture of leg stumps less frequently; Chopart stumps in equinus; forearm stumps with limited supination and arm stumps with limited abduction. The vast majority of the amputations were of the sagittal

Fig. 155

Fig. 156

(guillotine) type, or the modified sagittal with irregular skin flaps. These stumps usually showed a terminal circular or an irregularly shaped granulating area with partial marginal epithelization, often unhealthy in appearance, and

Fig. 157

Fig. 158.—Same as in Figure 157 after reamputation and healing

almost invariably giving positive cultures of staphylococcus and streptococcus, and occasionally diphtheria. A limited number showed visible sequestration of bone. Edema of the soft parts adjacent to the wound was the rule and its extent was dependent upon the degree and nature of the infection and upon the

site of the amputation, being more marked and more persistent in amputations below the middle third of the leg, and in the lower third of the forearm. It was evident in most cases in which primary aseptic amputations had been performed that the published official instructions regarding sites for amputation[13] had been adhered to. In spite of the fact that infection was the rule in stumps requiring secondary surgery, conditions were favorable when contrasted with those existent at the time of the primary amputation overseas. In the latter case the primary consideration was the eradication of a potential life-destroying pathological process with the minimum sacrifice of limb length, whereas under the comparatively favorable conditions existing at the time of the secondary stump surgery it was possible to give full consideration to the prosthetic and functional requirements of the stump.

Fig. 159.—Stump showing terminal edema and other evidences of latent infection

STUMP PATHOLOGY

Referable to Bone

In nearly every case it was evident that the bone as well as the soft parts had been exposed to infection with a resulting localized osteomyelitis of varying degree. The process of sequestration and involucratization, with associated low-grade infection of the adjacent soft parts, did not differ materially from osteomyelitis under other conditions; it was usually limited to the terminal portion of the bone on account of the fact that drainage was thorough. This terminal osteomyelitis was one of the chief causes of long delay in healing and required roentgenographic study and special treatment before secondary final plastic operations could be successfully done.

The most common type of sequestrum seen was ring-shaped, usually about 1½ cm. in thickness. It was usually loose and partially visible or palpable; less frequently it was more or less concealed by excessive bone production extending down from the bone cortex. In some instances it was seen to be practically encapsulated by new bone formation with a small sinus leading through the latter.

Excessive terminal bone production in guillotined stumps was the rule. The most common form was an irregular mushrooming, with a tendency to spurs on the inner aspect of the femur. Occasionally sharp exostoses were seen. These often were sharp enough and long enough to cause sufficient pain to warrant their removal.

Interosseous bony union was seen in both the forearm and leg. In the former, operative interference was instituted only when the forearm stump was long enough to preserve the movements of pronation and supination. Treatment consisted in removing the connecting bony overgrowth and the inter-

FIG. 160.—Typical ring sequestrum

position of muscle. Obviously in the leg this condition is helpful rather than detrimental, unless associated with terminal sharp exostoses.

Displacement of the patella in the Stokes-Gritti amputation and of the portion of the os calcis in the Pirogoff operation were seen. Nearly all ampu-

tations of the types were unsatisfactory and required additional surgical treatment.

Comminuted fracture complicated by extensive osteomyelitis of the shaft was met with occasionally. Preliminary treatment of the osteomyelitis was of course instituted before stump surgery was attempted.

FIG. 161.—Complete ring sequestrum surrounded by new bone formation. The stump is healed except for small sinus from the sequestrum

Inequality in the lengths of the bones in amputations of the forearm and of the leg occasionally demanded correction. In leg amputations the prosthetic requirement that the fibula be approximately 2 cm. shorter than the tibia, as a rule, had been met in primary amputation. In certain short leg stumps it had evidently been possible at the primary amputation to save several inches of fibula but a much smaller amount of tibia. Such cases naturally form an exception to the general rule.

Referable to Soft Parts

Stumps with redundant soft parts were seldom found. When this condition did occur it was usually associated with late necrosis of bone or with

Fig. 162.—Excessive terminal bone production, "mushrooming." Note that muscles are above this area

extensive comminution of bone without equal damage to the soft parts, in which case it was, of course, wise to save all viable soft parts available, as thereby greatly facilitating the late plastic surgery. The secondary removal

of soft parts for surgical or prosthetic reasons was not done until the necessity for and the possibility of utilizing them in connection with osteoplastic methods to increase the length of the stump had been considered.

FIG. 163.—Bony spur in below-knee amputation

Tender nerve ends occurred most frequently in amputations of the upper extremity. They seldom make themselves manifest until an appliance has been worn, so that in the treatment of unhealed stumps it was considered safest to assume that every nerve which was palpable might give trouble, and

its treatment was indicated at the time of the secondary plastic procedure. Simple high division after crushing and ligature seemed to give results equally as good as those obtained after more elaborate neuroplastic methods.

FIG. 164.—Interosseous bony union in below-knee stump. Spurs

PREOPERATIVE AND NONOPERATIVE TREATMENT

In a preliminary report of experiences in treating the first 500 cases, published in 1919,[14] a very conservative policy in the surgery of unhealed stumps was advocated. It seemed then that by the use of skin traction and other

nonoperative measures, healing could be obtained in a reasonable time and that secondary operative surgery of the stump could be dispensed with in the majority of cases. Subsequent experience showed that it was impossible to obtain complete healing in guillotined stumps, but that a very long time was required and that the resulting scar was not sufficiently tolerant of the usual traumas of an appliance to be practical. It was also found that many stumps either actually required reamputation at a higher level or that a limited amount of bone could be removed without damaging the stump from a functional viewpoint; so that finally plastic methods designed to obtain a firm closure, with freely movable skin, were employed usually before cicatrization was complete.

The importance of surgical rest and in most cases actual recumbency in the treatment of large infected wounds of the extremities was frequently observed and can not be too strongly emphasized. Nothing was gained by hastening prosthetic treatment to the point of applying temporary prosthesis before the stump was considered surgically sound. In the majority of cases it was found best to treat all cases judged to require secondary surgical procedures in recumbency until wounds were in the required condition for operation. It was noted repeatedly that wounds which had remained practically stationary under ambulatory treatment would promptly improve in recumbency.

Skin traction was used as a matter of routine both in recumbent and ambulatory treatment. In the former, direct extension was employed by means of adhesive strapping with pulley and weights and in the latter counterextension with a modified Thomas splint. It is interesting to note that the former method is accurately described in "The Medical and Surgical History of the Rebellion."[15]

Traction was, of course, most effective when applied immediately after the amputation. Its effect then was to actually reduce the extent of uncovered area. If it had not been applied early and the skin had been allowed to retract and to become adherent to the edges of the ulcer, traction did not tend to reduce the unhealed area materially, but it relieved tension at the edges, thus favoring healing, and was particularly helpful in subsequent plastic operations by rendering the skin more redundant. In a few cases in which there was wide retraction of the skin in short stumps, it seemed best to dissect the skin free and then apply traction for a time before attempting final plastic closure. The favorable influence of stump traction in the prevention of joint contractures was repeatedly observed.

WOUND ANTISEPSIS

The Carrel-Dakin routine treatment was used in all infected stumps as long as the unhealed area was large, concave, and discharging pus freely. Dichloramine-T was substituted when the wound became smaller in area, the granulations healthy and reasonably clean.

Massage of the terminal part of the stump was found to be beneficial in several ways. In healed stumps with small scar areas adherent to bone, massage was effective in loosening the scar and improving its circulation and thus increasing its tolerance to trauma. In unhealed stumps massage of the skin

adjacent to the scar area assisted in removing edema and generally improving the circulation, as well as rendering the skin free and more redundant preparatory to the final plastic procedures.

ATTENTION TO ADJACENT JOINTS

The following prophylactic measures against joint contractures were used: In so far as it was possible, the recumbent position of the patient and the adjustment of traction was such that the usual contractures would tend to be prevented. At each dressing the stump was moved to the full limit in the opposite direction to that in which a contracture was most likely to develop.

WHEN SECONDARY STUMP SURGERY SHOULD BE DONE

Attempts to perform early secondary closure of infected guillotine stumps resulted in a high percentage of failures. It seemed that the most important factors causing the failures were (1) the poor general condition of the patients following the more or less recent severe trauma on the battlefield in conjunction with the subsequent operative and postoperative treatment, and (2) absorption of toxins from latent infection of the stump, which is not only present in the terminal granulating area, and in many cases in the terminal portion of the bone, but, as has been conclusively shown by Huggins [16] and others, also exists in the lymphatic channels for a considerable distance proximal to the unhealed area.

It was found that it was not justifiable to attempt plastic closures or reamputations adjacent to the unhealed area until at least five or six months had elapsed from the time of the original injury. An attempt was made to establish definite preoperative indications by bacterial counts from the wound surface, but it became apparent that this method of control was not reliable, as it gave no exact indication of the extent of latent infection in the lymphatic channels further up the limb. It was found better to depend upon observations referable to the clinical appearance of the stump and the general condition of the patient.

As long as the stump remained swollen, boggy, and edematous it was found that there was latent infection present which defeated attempts at plastic closure. The disappearance of the edema was usually coincident with the gradual improvement in the general condition of the patient and in the local appearance of the unhealed area. Final closure was deferred until (1) the skin and subcutaneous tissue was soft, dry, and wrinkled, freely movable and absolutely free from edema, (2) all sinuses leading to bone or other foreign bodies had been radically treated and cured, (3) cultures from the unhealed area were free from streptococcus and the field count was reasonably low (less than five to the field) for other less virulent pyogenic organisms.

OPERATIVE TREATMENT OF UNHEALED CASES

From the standpoint of treatment stumps could be conveniently and advantageously divided into three distinct groups, as follows: Group I.—Stumps in which a limited amount of bone may be removed without diminish-

ing the ultimate functional value of the stump. Group II.—Stumps which are already too short and which will, consequently, not permit of additional sacrifice of bone. Group III.—Those in which sagittal amputation has been done at a site considerably distal to the ultimate secondary site to be selected.

Group I

The question of bone length required careful consideration in every case, and there were times when it was justifiable to sacrifice ideal conditions regarding the soft parts in order to preserve it. On the other hand, in perhaps the majority of the sagittal amputations, little was lost in ultimate function by removing a limited amount of bone and much probably was gained by the additional freedom allowed to eradicate more thoroughly tissues subject to

Fig. 165.—Long thigh stump requiring secondary plastic operation. Example of Group I

possible pathological changes in the terminal portion of the infected stump. The following are examples in this group: Sagittal amputations 9 inches or more below the knee-joint; infected sagittal knee-joint amputation. Before attempting final plastic closure of stumps in this group it was necessary that all indications previously pointed out regarding the proper time to operate be present, except that the actual size of the unhealed area could be safely disregarded.

The following method seemed to give the best results and was quite generally used: The unhealed area and the scar are completely covered with a gauze sponge which has been saturated with tincture of iodine. The incision is now made in healthy skin one-half cm. from the edge of the scar. It should follow the general contour of the scar area. No attempt should be made to form specially designed skin flaps. The distal skin is clipped to the iodined

gauze as the incision is being made, thus completely isolating the terminal infected area. The skin and scar are then dissected distally, separating them from the muscle, to the place where the latter are attached to the bone. It will usually be found that this is above the area of new bone production and well away from the unhealed area, usually 1 to 1½ inches. The periosteum is incised just within the area of fibrous tissue which extends somewhat distal to the muscle fibers. The bone is sawed at this point. If the preoperative treatment has been properly carried out and the scar area is not excessive, it will now be possible by careful disposition of the skin to cover the end completely. If it is found that the available skin is not sufficient, additional bone or muscle may be removed. It is better to avoid cutting through the muscles and deep vessels. The nerves are found usually by palpation and should be pulled down and severed through a small longitudinal incision in the muscles. The wound should be drained for 48 hours through a posterior stab wound This type of drainage was found to be preferable because it gave the best drainage, being dependent, and, in the event infection occurred, sufficient drainage was afforded to prevent the incision line from separating. Primary union in the incision line was often obtained and maintained in the presence of purulent discharge which was satisfactorily taken care of through the posterior drainage incision.

Group II

In this group it was found to be imperative that at least six to eight months should have elapsed since the initial injury and that in addition to the preoperative requirements already enumerated, it was preferable that the wound be completely cicatrized or that the unhealed area be very small and practically sterile.

The aim of operative procedures in this group was to remove intolerant scar and to replace it by freely movable healthy skin. The following methods were used and found successful.

In short below-the-knee stumps the presence of the fibula is usually not desirable; moreover, by its removal, sufficient skin can be mobilized to cover successfully a fair-sized scar area. In addition, muscular tissue of the calf may be removed quite extensively without injuring the stump in any way. In conjunction with these measures it was usually necessary to employ one of the following methods of skin mobilization: (1) Single or double pedicle swing, in which case flaps of skin and subcutaneous tissue of various shapes were swung from the lateral surface to the terminal surface of the stump, closure of the donor area being accomplished by diminishing the circumference of the stump. (2) Double pedicle transplant. A rectangular flap taken from the posterior was dissected free and moved to a terminal position with double pedicles, internal and external. This method was very successful in short leg stumps with a broad, smooth, bony surface. Total end bearing was usually made possible. (3) Distal pedicle transplant. This is a well-known method and requires no further mention here.

In short thigh stumps closure was usually made possible by using the single pedicle swing flap. Occasionally it was necessary to remove a limited amount

of muscles. It was found best to remove a triangular section with the base external. Muscles on the inner surface could be removed with the least damage.

Thiersch and Reverdin grafts were occasionally tried. Healing was of course hastened, but closure was not firm enough for practical purposes.

Group III

Amputation through the ankle joint may be cited as an example of this group. In this case the Syme amputation could not be considered, as sufficient soft parts are not available, so that the middle and lower third of the leg is the site to be selected. Another example is sagittal amputation one-half inch below the knee joint, requiring a formal amputation. In this group it was possible largely to disregard pathology referable to the terminal part of the stump and to proceed with the final amputation much earlier than in the other groups. In all cases, however, it was found advisable to adhere strictly to the rules regarding delay until the general condition was sufficiently improved to withstand a major surgical procedure, and to those regarding edema of the soft parts and associated lymphangitis and lymphadenitis. The treatment in this group was formal reamputation.

A reamputation is equivalent practically to a primary amputation under ideal conditions and necessarily involves careful consideration regarding the site of amputation and its influence upon the ultimate functional result. The value of a stump in terms of function can be correctly estimated only when the stump and its prosthesis are considered as a composite functioning unit. It follows then that in order to choose the proper site one must consider carefully the comparative value of prosthetized stumps.

SITE OF AMPUTATION OR REAMPUTATION WITH REFERENCE TO PROSTHETIC REQUIREMENTS

LOWER EXTREMITY

Foot

Phalangeo-metatarsal amputations and transmetatarsal amputations.—These were infrequent, but it was noted that amputations anywhere in the metatarsal area gave good function. All the bone length possible should be saved. It is a mistake, however, to attempt to preserve bone length in the foot at the expense of perfect skin covering. A scar on the foot healed by granulation, directly overlying bone, inevitably will ulcerate and cause intermittent disability which eventually will lead to a reamputation. Every effort should be made to obtain a dorsal linear scar, the ends of the bones being well covered with a plantar flap. The use of the distal pedicle transplant will sometimes obviate the necessity for reamputation in these stumps.

Lisfranc's amputation.—Amputation at the transmetatarsal joint gives reasonably good function. Dorsal flexion of the foot is better preserved by anchoring the dorsal flexors to the ends of the bones. The same general surgical considerations apply here as described for metatarsal amputations. The

only appliance necessary for this, as well as the former, is a filler for the toe of the boot and a steel inset in the sole to prevent turning up of the toe.

Transtarsal amputations.—Transtarsal amputations distal to Chopart's joint seemed preferable to Chopart's amputation, as proper balance of the dorsal and plantar flexors of the foot is better preserved. However, the same prosthetic objections apply to this amputation as to the Chopart.

Chopart's amputation.—Mediotarsal (Chopart's) amputation usually resulted in bad function for surgical as well as prosthetic reasons. The majority seen were sagittal amputations at this site, in no sense classical Chopart's amputations, but rather guillotine amputations at or near the mediotarsal joint. It was assumed that it was not the intention of the surgeons who performed the primary amputations that these should function as Chopart stumps. Most of them required reamputation. Attempts to improve them by plastic methods were usually not successful. The conclusion drawn from experiences in treating a limited number of classical Chopart stumps are as follows: (1) Surgical difficulties—(*a*) The type of injury requiring a Chopart stump seldom

FIG. 166.—A typical sagittal Chopart stump

leaves sufficient plantar flap to permit the scar being well placed on the dorsal surface. (*b*) Equinus deformity of the stump eventually develops in spite of efforts to preserve foot balance by tenoplastic procedures. As equinus develops the scar which is usually terminal and poorly vascularized is pressed upon, and end bearing, the greatest asset of this stump, must be forfeited. (2) Prosthetic difficulties—The stump is too short to properly anchor the necessary "fill" in the fore foot, so that constant friction between the toe "fill" and the end of the stump takes place, usually resulting in ulceration and consequent disability. Lack of stability in the toe part of the appliance prevents the necessary forward thrust in walking so that slight limp is invariably present. In many Chopart stumps it is necessary to anchor the fore foot by extending a steel rod to the ankle joint and connecting this by a joint to a steel upright which is laced to the leg. This appliance requires a special shoe with a very unsightly ankle.

The percentage of surgical successes in Chopart is so low and the prosthetic difficulties so considerable that it is not a justifiable amputation unless it is intended that a simple elephant boot be worn continually instead of the

articulated appliance. This point is mentioned because there are undoubtedly cases in which occupational considerations should predominate over the esthetic.

Pirogoff's osteoplastic amputation.—Two cases are recorded which required reamputation on account of displacement of the remaining portion of the calcaneum. The added risk of an osteoplastic procedure is not compensated for in any way, as the percentage of total end-bearing stumps following the Syme amputation is quite as high as in the Pirogoff. The added length in the Pirogoff requires that the other shoe be raised at least an inch to make up for the space required for the ankle movement.

Syme amputation.—The chief advantages noted in the perfect Syme amputation were that it is total end bearing and that the length of the limb is approximately preserved, so that the patient can move around in the nude without his appliance, and that either the straight boot or the appliance with an articulated foot can be worn with reasonably good function.

Unfortunately, the percentage of perfect Syme stumps was not high. Failure was usually attributed to one or more of the following causes: Sloughing of the planter flap due to cutting the pedicle too narrow; lateral displacment of the flap; sawing the bones at right angle to the terminal axis of the tibia rather than to the long axis of the leg; making the bone section too near the joint to allow space for the mechanism of the artificial ankle.

Functionally, a perfect, total end-bearing Syme stump is a satisfactory stump. The choice between this amputation and one at the ideal site in the leg is one which involves an analysis of the occupation and habits of the patient. A laborer is better satisfied with the Syme amputation because he can wear a straight, nonarticulated boot during the working hours, and he is less likely to be dissatisfied with the bulky, unsightly ankle mechanism when "dressed up" than a professional man, for example, would be.

The Leg

Amputations in the lower third.—The rare opportunity of observing a considerable number of amputations in the lower third of the leg was offered. All required reamputation mainly on account of poor vascularity and associated complications. Nothing is gained by the additional bone length in these stumps, as excessively long leg stumps interfere with proper shaping of the ankle portion of the artificial limb and may actually interfere with the ankle mechanism.

Amputation at the ideal site.—Amputation through the middle of the leg, or a little below, as recommended in an official publication,[13] proved to be the preferable site. The essential points in the technique adopted were: (1) Long anterior and short posterior flaps, the scar line being posteroterminal; (2) circular division of muscles without suture or the use of a thin flap of muscle and facia sutured over the bone ends to prevent adherence of the skin to bone; (3) division of the fibula one-half inch higher than the tibia; (4) beveling of the tibial crest; (5) drainage when necessary through a small stab wound in the middle of the posterior flap.

The appliance for this amputation is simple, durable, and shapely. If the fitting is proper, disability is scarcely discernible. Stump tolerance to the appli-

ance is quickly acquired and the functional result is very gratifying to all concerned.

In amputations of the leg above this level every effort was made to preserve all bone length possible. When the amount of bone length that can be preserved with good soft part coverings is 3 inches or less, it is justifiable to sacrifice ideal conditions as regards the soft parts, if bone length may thereby be increased It was generally considered early in the war that it was not justifiable to attempt to amputate below the knee if the amount of bone length possible to be saved was less than 3 inches. Subsequent surgical and prosthetic developments warrant a revision of this opinion. In these cases the leverage may be increased. to the point of utility by removing the fibula, cutting away practically all of the muscular tissue on the back of the stump and severing the inner hamstring. Special study and experimentation in the prosthetic treatment of short stumps carried out at various clinics gave promise of increasing the functional utility of stumps not less than 2 inches in length, so that it seems best to defer reamputation until surgical attempts to increase bone length or to increase leverage by other methods have failed.

Fig. 167.—Transcondylar reamputation. Total end bearer

The Thigh

If it was not possible to amputate below a point 2 inches from the knee joint (bone length), the next best site proved to be the high transcondylar amputation. This excludes knee-joint amputations, all osteoplastic amputations at or immediately above the knee joint, and low transcondylar amputations. All of these are too long to allow the use of the standard artificial knee action and require a cumbersome and faulty mechanism outside the clublike stump. Osteoplastic amputation (Stokes-Gritti) offers nothing in function above the high transcondylar to compensate for a rather high percentage of

surgical failures (in three seen by the writer at Walter Reed General Hospital all required reamputation) and the prosthetic difficulties already mentioned. In the high transcondylar amputation the bone section is made at the point where the condyles begin to merge with the shaft. It is important to keep within the spongy bone just below the beginning of the medullary cavity proper. A long anterior flap of skin and quadriceps tendon is used. The scar is placed well posteriorly, away from the end-bearing surface. Surgical failures are few. Practically all of them permit total end bearing. Ample space is left to place the standard artificial knee action in the proper place.

Above the site for the high transcondylar amputation every effort was made to save all bone length possible to a point 2 inches below the lesser trochanter. All stumps having bone length of from 2 to 4 inches below the lesser trochanter require a pelvic band. This is an objectionable feature, so that a special effort was always made to preserve more than 4 inches, if possible. A stump having bone length of less than 2 inches below the lesser trochanter does not have sufficient leverage to operate the thigh appliance. The only choice, then, is to give a stump suitable for the so-called hip-joint appliance.

From a prosthetic and functional viewpoint the classical disarticulation at the hip is not preferable to amputation through the neck, which is much more quickly and easily performed. In the latter the mortality is lower, and the resulting stump is better adapted for the fitting of an appliance. It was not, however, considered justifiable to reamputate a stump too short to operate the usual thigh appliance for prosthetic reasons solely.

UPPER EXTREMITY

The rôle of the appliance in the functional utility of stumps of the upper extremity is considerably less important than is the case in stumps of the lower extremity. In fact, it is debatable whether or not appliances in the case of single amputations of the upper extremity are of sufficient value to constitute a deciding factor in the selection of site. The young soldier who has lost an arm is eager for his appliance, because he is desirous of masking his disability and because he hopes that it will be functionally useful. To his great disappointment, he soon realizes that it is indeed a poor substitute for either purpose. It has been found that approximately 60 per cent of individuals who have suffered the loss of a single arm do not find existing prostheses sufficiently useful to compensate for the inconvenience of wearing them, except occasionally for esthetic reasons. The following conclusions regarding sites are based upon the use and requirements of American prostheses existing at the time our amputation cases were being treated and do not involve a consideration of surgical and prosthetic experimental work being carried out in various foreign clinics during and after the World War, as opportunity for exhaustive study and practical applications of these appliances and methods was not possible in the short time offered.

The Hand

In primary surgery immediately following the trauma nothing more should be done than débridement, trimming the devitalized tissues, and establishing

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thorough drainage, the question of site being totally disregarded. The prevention of contractures of the fingers following infection and of the formation of scar tissue demands special attention from the beginning. In the secondary surgery of the hand radical alteration in the site of amputation is seldom advisable. The usual conditions demanding treatment are, sluggish, unhealed areas associated with localized osteomyelitis, or tender and adherent scars with deforming tendency. The latter condition usually demands special plastic procedures, the aim of which is to displace the scar by freely movable tolerant skin. The distal pedicle transplant gave the best results where it was important that no bone should be sacrificed. Usually a portion of a phalanx of any of the fingers except the index and thumb can be sacrificed without serious functional damage in order to obtain good soft part covering. The loss of the thumb or any part of it constitutes a serious disability. A badly damaged thumb, with loss of muscular power or ankylosis, or both, is preferable to no thumb at all. Heroic efforts at reconstruction of the thumb are justifiable. One case in which a thumb stump was lengthened one-half inch, with gratifying functional improvement, has been reported.[17]

Prostheses for amputations of individual or multiple digits are very useful but are usually inferior to even a severely mutilated stump. They are most useful if the thumb is amputated or if all except the thumb are gone, as apposition is made possible by their use. If sufficient of any of the fingers remain to make active apposition possible, prostheses are seldom worn except for esthetic reasons.

Transcarpal amputation is preferable to amputation at the wrist even though there may be an adherent terminal scar. The latter can be repaired by distal, pedicle skin transplant.

Wrist-joint amputation is distinctly preferable to any higher up, as pronation and supination are better preserved, and the fitting of an esthetic hand or a work appliance is facilitated by the more or less club-like end of the stump, which permits the elimination of much attachment apparatus.

The Forearm

Amputation in the forearm should be done as low down as possible. In the lower third circulation is often poor, but usually not troublesome enough to warrant amputation higher up solely on this account. Primary amputation should seldom be done higher up for this reason, and reamputation should not be considered unless all efforts to improve the circulation have failed. The importance of preserving pronation and supination warrants special attention to surgical details; i. e., careful treatment of the periosteum to avoid shredding and consequent overproduction of bone and the interposition of muscle to prevent bony bridging.

No matter how short a forearm stump may be, it should not be sacrificed, as in the majority of cases a forearm stump, no matter how short, is more useful without prosthesis than an upper-arm stump either with or without an appliance. They should never be shortened to correct inequality in the length of the bones. Tender scars or scars objectionable for any reason should not be corrected by the

sacrifice of bone, but by plastic methods involving the soft parts only. The presence of redundant soft parts in this region constitutes an indication for plastic methods to increase length rather than for their removal.

The Upper Arm

Transarticular and transcondylar amputations are generally considered objectionable from the standpoint of existing prosthesis, because the fitting is difficult and there is inconvenience to the patient in applying and removing the apparatus. Moreover, the artificial joint must be placed lower than normal. On the other hand, experience shows that in single amputations less than 20 per cent of persons with amputation of the upper arm wear appliances. Of these it is reasonably safe to assume that the majority are wearing a practical (work) appliance rather than the dress-up type. The newer types of the former, are more securely fitted with less "harness" if the bony prominences of the condyles are present, so that before deciding upon the sacrifice of the condyles a careful analysis of the requirements in the individual case is necessary. The transcondylar is preferable to the transarticular amputation n any case. Above this all bone length possible should be saved.

It was found that short arm stumps could be improved as regards leverage by severing or raising the insertions of the pectoralis muscles, the latissimus dorsi and the teres major. The humeral head should always be saved if possible, as the shoulder contour is preserved thereby.

In double amputation of the upper extremities the necessity for prosthesis is unquestionable, so that the rules regarding site for amputation as influenced by prosthesis and previously outlined [18] apply more forcibly here. The most successful cases of double amputation seen, however, were those using special, usually self-designed, appliances particularly adapted to their individual requirements. In the latter case the more conservative surgical methods would be most applicable.

CINEMATIZATION OF AMPUTATION STUMPS

Cinematization of stumps is accomplished by connecting at the end of the stump the antagonistic muscles, or by giving them artificial insertion into the prosthetic apparatus.

In July, 1918, the report of a special committee directed to investigate the question of cinematization was available for the information of those engaged in amputation work.[19] Briefly the conclusions of this committee were that cinematization was still in the experimental stage and that it could not be recommended except as an experimental procedure and that it should not be attempted unless adequate facilities were available for pursuing the experimental prosthetic work necessarily associated with it. No doubt the few who were interested felt that they were not adequately fortified with the requisite knowledge and experimental facilities to undertake this work on a really progressive scale. Three cases were done in the base hospitals in the United States and two cinematized stumps were returned from overseas.[20] In only one of these cases was the final functional result a distinct improvement over that obtained with the usual methods. Two were failures and required excision of the tunnels. Lack of

success was due to failure of coordination in the surgical, physiotherapeutic, and prosthetic treatment, which resulted from the frequent transfer of patients and perhaps in a measure to the breaks in follow-up coincident with frequent changes in personnel after the beginning of the armistice.

POSTOPERATIVE TREATMENT

In all stumps in which there was even moderate tension, traction straps were applied in the operating room. It was found best not to apply weights in undrained cases until the following day, unless tension was marked. In the average case of this type, traction, if applied at once, seemed to favor oozing and the accumulation of clot. In addition to the advantages of traction previously mentioned, there seems to be no doubt that it adds to the comfort of the patient by preventing muscular spasm and that it is instrumental in preventing postoperative hemorrhage in the same way.

Blood drainage was removed in 48 hours. In case secondary hemorrhage occurred, with ballooning of the flaps, it was found best to remove the sutures, clean out the clot, and reapply traction. Secondary infection was the rule in all cases in which special attention had not been given to the elimination of dead spaces and in those in which secondary hemorrhage occurred.

After the wound was healed, massage of the muscles was begun. Adjacent joints were moved passively once daily through the full range of motion. After healing was firm, if the patient was able to be out of bed, he was sent to the shop for his provisional fitting. Daily baking and massage was continued after fitting, in order to remove edema and to generally improve the circulation. The stump was bandaged at all times when the appliance was not being used.

USE OF PROVISIONAL APPLIANCES IN AMPUTATIONS

LOWER EXTREMITY

In all stumps of the lower extremity, with the exception of partial amputation of the foot and the Syme amputation, a portion of the stump is called upon to function in a manner entirely new and for which it is poorly adapted, i. e., weight bearing. Radical physiological changes necessarily take place in the weight-bearing portion of the stump, pressure atrophy of the soft parts; increased tolerance of the skin to lateral pressure from the encasing socket of the appliance; development of balance and sense of position; tolerance to pressure on and adjacent to bony prominences. The other important task of the stump leg is propulsion of the limb and its appliance. In spite of the fact that the artificial limb is not as heavy as the amputated part, more power is required in swinging it on account of its comparative inertness. Increased difficulty in balancing undoubtedly adds to the demands made upon the muscular power of the proximal part of the stump leg. The preservation of normal muscular power, or better the development of increased muscular power in the proximal part of the stump leg, is of vital importance. Since certain definite physiological changes must take place both in the stump and the proximal part of the leg before a stump can be considered functionally fit for a permanent appliance, it is clearly the duty of the surgeon to use all methods

at his disposal to hasten these changes and to obtain a good functional as well as a good surgical stump before a permanent appliance is used.

Principles of Fitting

Weight bearing in the case of below-knee amputation is distributed as follows: Cone bearing (lateral surface bearing); bony prominence bearing (head of tibia, tuberosity of tibia, fibula below head); partial thigh-surface bearing (thigh cuff); and, in a certain percentage of cases, end bearing. In a finished appliance the stump is incased in a solid shell which is molded or carved to fit the stump in such a way that all the bearing points and surfaces are used to a variable degree. The physiological changes in the stump will depend largely upon the predominating type or types of bearing chosen in a particular case.

Cone and bony prominence bearing with slight partial thigh bearing are found to be applicable to most leg stumps except in the Syme amputation. Pressure atrophy is rapid and marked, consequently repeated remolding of the socket is imperative. End bearing diminishes pressure atrophy of the stump. In amputation of the thigh, bony prominence bearing (ischial tuberosity) cone bearing, and, in certain cases, end bearing, are utilized. Bony prominence bearing predominates so that pressure atrophy of the stump is slower and less marked than in leg stumps. End bearing has the same relative advantages, but to a lesser degree.

Undoubtedly end bearing is possible in a high percentage of stumps; success in obtaining it is largely dependent upon faithfulness and persistence in carrying out the necessary preliminary measures to increase the tolerance of the end of the stump. Experience has proven that a definite distinction must be made between total and partial end bearing, and that in certain instances end bearing may not be desirable, i. e., in long, below-the-knee stumps. Cone and bony prominence bearing have given nearly perfect function. If end bearing is attempted in these stumps it is found that there is a certain lack of adhesion between the appliance and the stump and that the gait is not as good as with cone bearing. In thigh stumps of moderate length total end bearing is not preferable to ischial and cone bearing for the same reasons. There is little doubt that partial end bearing is always an advantage.

The following stumps, in addition to partial foot amputations, were found to be especially well adapted for end bearing: (1) The Syme stump; (2) short below-knee stumps, and (3) that resulting from a transcondylar amputation. The bone section in each of these is through spongy bone, which seems to give a more tolerant end bearing surface. Each is clubbed more or less on the end, which favors proximal methods of attachment of the appliance, thus avoiding instability of the appliance mentioned above.

An ideal provisional appliance should possess, in the main, similar mechanical features to those found in permanent appliances. The socket should be of solid material and should be molded or carved in the same accurate manner, as in a permanent one. Excavations and additions which are customarily made to influence bearing on certain definite points, which are known to be adapted for this function, should be carefully made. A provisional appliance which

merely shrinks the soft tissues of the stump and does not develop the tolerance of the bearing points and surfaces, which will be called upon to function in a proper permanent appliance, is not an efficient provisional appliance. The provisional socket must be one which can be remolded frequently and comparatively inexpensively. In addition to changing shape, in a certain percentage of cases it is not only desirable, but necessary to change the position of the socket so that a complete change of socket rather than a reshaping is sometimes necessary. This feature is important in all cases in which there is more or less malposition of the stump, which is gradually being improved by the use of the appliance.

FIG. 168.—Temporary appliance—plaster socket; stock metal bars; wooden foot. This was the best type of temporary appliance

Various types of temporary appliances were used in the different centers. In most of them the socket was made of plaster-of-Paris and the framework of wood or metal. In one center a papier mâché socket was used and found to be very satisfactory.

The soldier with a recent amputation usually is most concerned in removing his physical deficiency as soon as possible from an esthetic rather than from a functional standpoint. Pegs and the cruder types of temporary appliances were strenuously objected to by a fair number of patients. After the provisional type of appliance was available in quantities, very few pegs were used. There seemed to be no advantage in delaying the fitting of the standard provisional appliance, inasmuch as it was even more versatile as regards refitting than pegs and the cruder temporary appliances. An attempt was made to utilize a provisional leg which in all respects looks like a finished leg. Of necessity it was adjustable as regards length, foot position, and socket. The

FIG. 169.—This and Figure 170 show original models of stock provisional appliances for thigh and leg amputation. An adjustable leather cuff was used to effect refitting

socket adjustment was accomplished by supplying a rather large number of stock sizes, and by means of a leather cuff which could be adjusted to the shrinking stump by lacing.

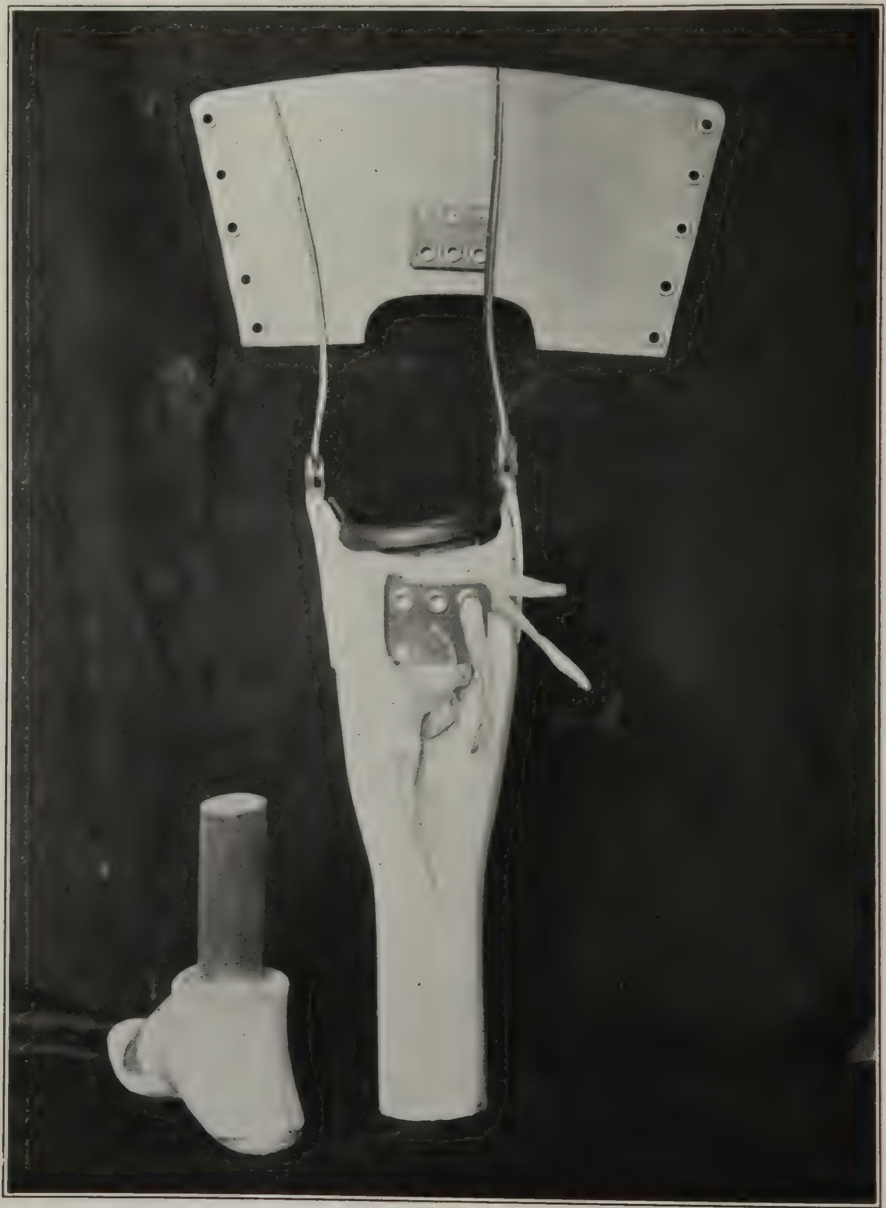

Fig. 170

In addition to meeting the esthetic requirements more satisfactorily than the temporary appliance, it offered the advantage of quantity production and quicker fitting. While this type of appliance was not applicable to as high a percentage of cases as anticipated, it was used in all centers except one, until supplemented by a more versatile type.

In thigh amputations this type of finished provisional leg was entirely satisfactory and in about 85 per cent of cases where there was sufficient bone length to operate the ordinary thigh leg. Most of the remaining 15 per cent fell into the class of excessively long stumps. It was not possible to fit these on account of interference of the mechanism for the adjustment of length. The greater part of the weight is taken on the tuberosity of the ischium and

FIG. 171.—Provisional appliance used at Letterman General Hospital

accurate cone bearing is relatively unimportant, consequently the cone fitting does not need to be very exact. In leg amputations the task of fitting this type of leg was much more difficult. Bony prominences are more numerous and less tolerant to weight bearing. Consequently, the bony prominence fitting must be more accurate and a greater amount of weight bearing must be allotted to the cone fitting. For this reason the latter must be more precise.

In order to meet the requirements of the more difficult cases which it was not possible to fit with the original model of the stock appliance, a more versatile type was developed and the stock parts (framework) manufactured

FIG. 172.—Letterman General Hospital artificial leg, assembled and unassembled

in quantity, in a variety of sizes; the only essential difference from the original model being that, instead of making the necessary refitting, by means of a leather-laced cuff, a plaster-of-Paris refitting was substituted in leg amputations.

The plan generally adopted in all amputation centers was to fit the stump with a temporary appliance as soon as healing was complete, but not to hasten the prosthetic treatment at the expense of a good surgical result. The appliance was worn at first to the limit of tolerance,

FIG. 173.—The final model of provisional leg with a plaster of Paris inset

special care being taken not to damage the soft parts. The part of the appliance which incases the terminal part of the stump, commonly called the socket, was changed and refitted as pressure atrophy progressed. Three changes were usually required. Deformities and surgical defects of the stump, i. e., bony spurs, latent infection and tender nerves, will be readily discovered and should be treated during this preliminary prosthetic treatment. Stumps were not fitted with a permanent appliance until they were surgically sound, pressure atrophy of the weight-bearing portion well advanced and the propulsive musculature of the proximal part of the leg well developed. The stock provisional appliances used were found to be sufficiently durable to last from eight months to one year. Six months preliminary prosthetic treatment was usually found to be sufficient to prepare stumps for permanent appliance.

Partial amputations of the foot, Syme stumps, end-bearing knee-joint amputations, and disarticulations of the hip as a rule were not fitted with provisional appliances. During the earlier experimental period a few were fitted in the appliance shops largely for experimental reasons. In these stumps the fitting is difficult and there is so little change in the stump as compared with those in which cone and bony prominence bearing predominates that there seems to be no reason to delay the permanent fitting.

UPPER EXTREMITY

The use of provisional appliances in amputations of the upper extremity does not seem to be so essentially necessary from the standpoint of fitting as in those of the lower extremity. The physiological changes in the stump from the use of the appliance are not marked enough to necessitate frequent refittings and it is not necessary to have so exact a fitting as in lower extremity stumps. The chief advantages in provisional fitting are that (1) immediate fittings are possible, which would not be the case in the time of war if permanent appliances were supplied by the artificial limb industry; (2) an opportunity is given to coordinate the surgical, prosthetic, and physiotherapeutic treatment and to carry out a reeducational program which is often more helpful than the appliance, per se; (3) surgical defects of stumps become apparent while the patient is still under Army control and can be corrected at once; (4) the patient has an opportunity to learn something about appliances which enables him to make a more intelligent choice of a permanent appliance.

The first appliances used were of simple design and rather crudely made. The socket was of plaster of Paris. In the end of the socket was incorporated a metal clamp to hold various implements. Later an inexpensive arm with a universal end attachment plate in which a hand, tools, or any type of hook or other useful device could be used interchangeably was adopted. The metal parts were manufactured in quantity and issued to amputation centers. Sockets were made of leather, the work of fitting being done in appliance shops. No originality can be claimed for this appliance, as similar types were already being used abroad. Workmanship and exactness of fitting was probably

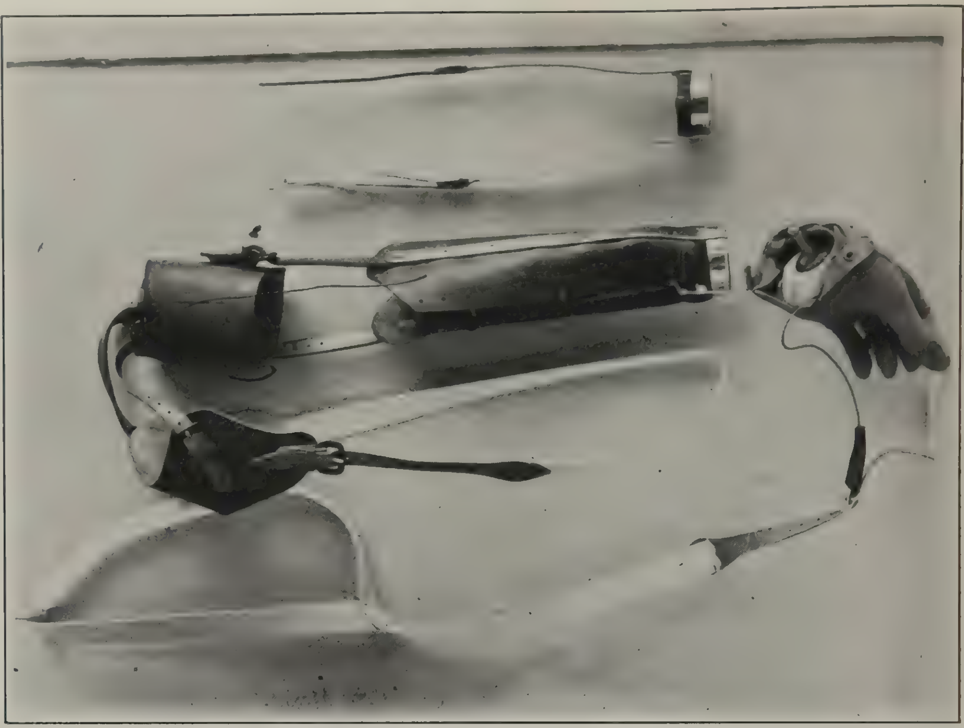

Fig. 174.—This and Figures 175 and 176 show the type of provisional arm used, and various attachments for work and play

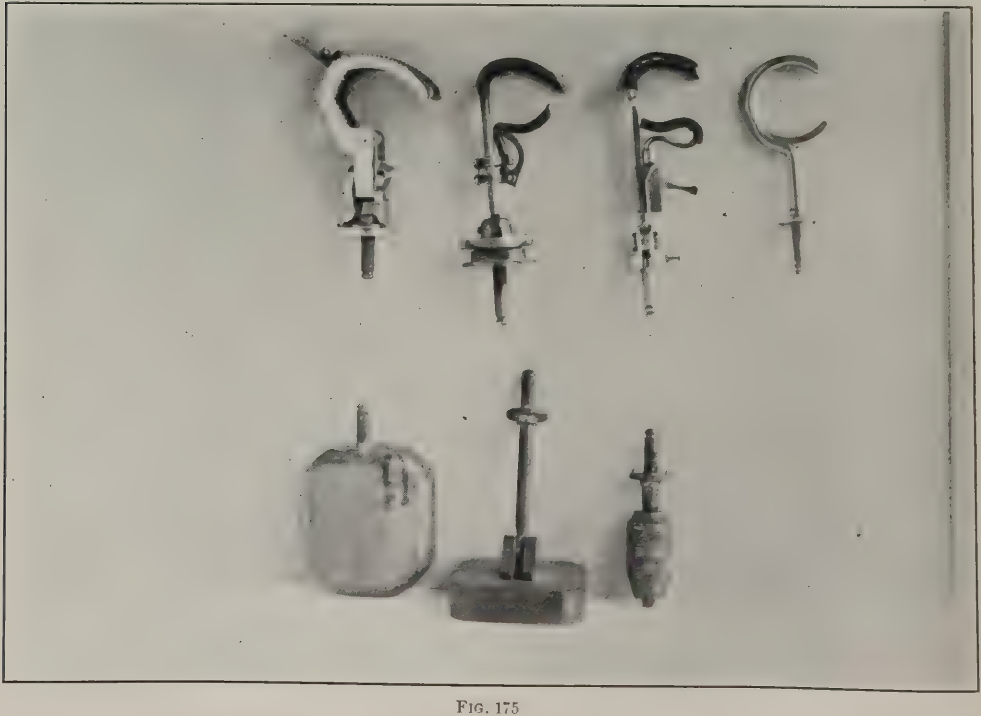

Fig. 175

not equal to that obtainable in the open market, but it is believed that it served the purpose as a provisional appliance as well as could have been expected from any single type of appliance obtainable.

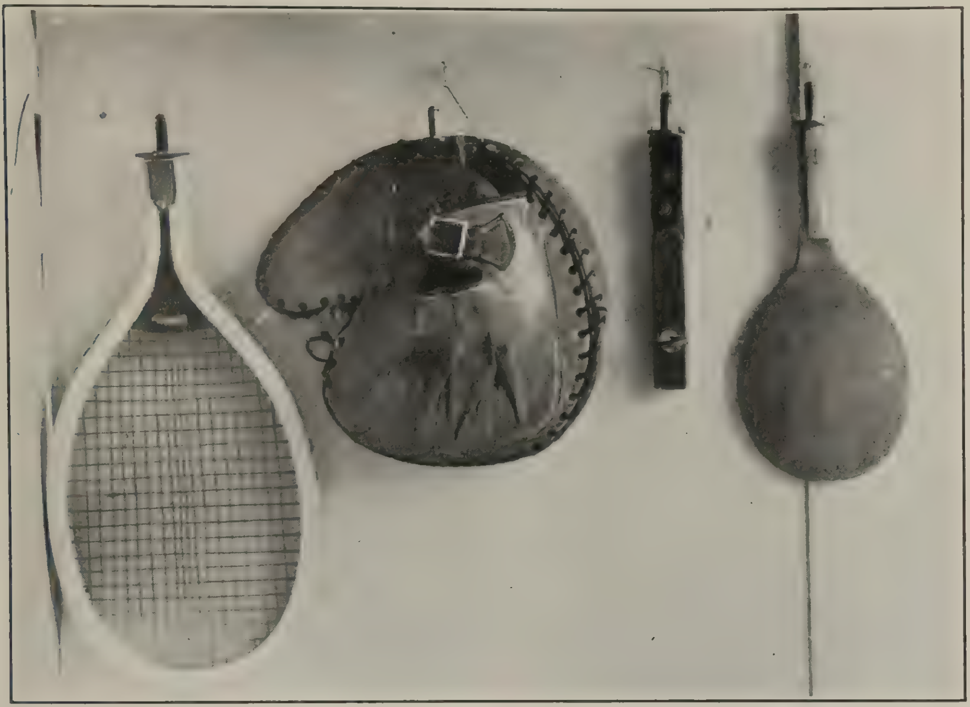

Fig. 176

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SECTION III

NEUROSURGERY

CHAPTER I

ORGANIZATION AND ACTIVITIES OF THE NEUROLOGICAL SERVICE AMERICAN EXPEDITIONARY FORCES [a]

In June, 1918, upon the reorganization of the professional services of the American Expeditionary Forces, neurological surgery was made a separate subservice of the genaral surgical services, and a senior consultant was appointed thereto.

PROBLEMS OF ORGANIZATION

No precedent covering the activities of such a subdepartment of general surgery existed in either the French or British Armies. Moreover, no figures were available which would serve to give an idea of the probable responsibilities of this service beyond the rough estimate that 25 per cent of all surgical casualties presented neurological problems of one sort or another. More or less unofficial figures from British and French sources had given the following percentage of injuries of the nervous system in relation to the wounded: For wounds of the head, including all types, 16 per cent;[b] for wounds of the spine, 2 per cent; for wounds of the major peripheral nerves, 20 per cent of all serious injuries of the extremities.

The problem, so far as could be seen, divided itself into two main parts: (1) The immediate care in forward hospitals of the more serious cranial cases; (2) the later care at the base hospitals of the residual paralyses of the main peripheral nerves, the neurosurgical aspects of which were not likely to come into prominence until the complete healing of the complicating wounds and fractures.

The results of the early operations for penetrating wounds of the skull, so far as figures rendered them available, had been lamentable, the estimated operative mortality from reports in literature varying from 50 to 65 per cent, and of all spinal cases about 80 per cent.

So far as the peripheral nerves were concerned, it was known that they had been accumulating during the four years of war in the French and

[a] Being the report to the chief surgeon, A. E. F., from the senior consultant in neurological surgery on summary of activities of the department, dated Neufchateau, December 2, 1918. Copy on file, Historical Division, S. G. O.

[b] The exact figures from two mobile hospitals operating in the Argonne in October and taking only seriously wounded were as follows: Out of a total of 1,202 cases, excluding those marked "multiple G. S. W." there were 135 head cases, giving 11.1 per cent. At this time no figures from a field hospital for seriously wounded were at hand and the proportion of head cases to other wounded, owing to the many early fatalities from wounds of this sort, naturally fell off greatly in the hospitals of the intermediate and base zones.

British hospitals and that great numbers of them were awaiting neurological study and neuroplastic operation or orthopedic procedures to ameliorate deformities.

PLAN OF ORGANIZATION

TEAMS FOR HOSPITALS IN THE ZONE OF THE ADVANCE

Obviously the most urgent need in June, 1918, was to supply the hospitals in the zone of the advance with surgeons who had had some neurological training and experience with penetrating wounds of the skull. As the available number of such officers was small, it became necessary to select and give personal instruction to one surgeon from each evacuation hospital and to supply the proper surgical equipment.

REPRESENTATIVE IN BASE HOSPITALS

In the emergency it was regarded of secondary moment to include in this plan the hospitals at the base, though provision was made so far as possible to have a representative surgeon in each base hospital who, even without much neurological experience, could work in conjunction with the neuropsychiatrist of the unit. Later on, some of the commanding officers of the larger hospital centers cooperated in the secondary routing within the particular center of the majority of the organic lesions of the nervous system to one hospital where they could be more satisfactorily supervised.

NEUROLOGICAL CENTERS

It was planned eventually to establish in certain favorable areas centers devoted exclusively to diseases of the nervous system, corresponding to the French neurological centers, where neurological cases might be assembled and where groups of experts, neurologists, neurosurgeons, and orthopedists with neurological interest, could be gathered and thus bring less strain upon a meager personnel. Such a plan, however, could be realized in a very small way only, largely in view of the fact, as is explained below, that relatively little time intervened between the inception of the subservice of neurological surgery in June, 1918, and the signing of the armistice the following November.

ARRANGEMENTS FOR THE CARE OF HEAD WOUNDS

SPECIAL SURGICAL INSTRUMENTS

For success in this work, special surgical instruments not contained in the Army equipment were essential, and only after some delay the necessary perforators, drills, and rongeurs were secured through French manufacturers.

INSTRUCTIONS FOR NEUROLOGICAL SURGEONS

In addition to the practical instruction in craniocerebral surgery given to selected surgeons from the various evacuation hospitals, the following directions were prepared by the senior consultant in neurological surgery, American Expeditionary Forces, and were furnished to members of neurosurgical teams.

DIRECTIONS TO NEUROSURGICAL TEAMS CONCERNING CRANIOCEREBRAL WOUNDS

It is expected of all neurosurgical teams that they shall primarily be capable of the general surgical work of a forward hospital. This is so, firstly, because multiple wounds are common and a compound fracture of an extremity or any other injury may accompany the head wound; secondly, because neurological cases may not happen to be admitted in sufficient number to occupy the full time of the team, or the situation may be such as to render advisable their early evacuation, untreated, to the nearest base. At best a well-trained team can hardly expect to cover on an average more than 8 or 10 cases of penetrating craniocerebral type in a working day.

It is requested that, on the form shown below, each neurological team send a monthly report of its cases to the senior consultant in neurological surgery, A. P. O. 731:

TO THE SENIOR CONSULTANT IN NEUROLOGICAL SURGERY
MED. & SURG. CONSULTANT HQ. A. P. O. 731,
A. E. F.

REPORT OF NEUROSURG. TEAM NO. ---- AT----------
HOSP. NO. ------ FOR THE MONTH OF ---------- 191--

SIGNED---

Name, rank, and organization	Serial No.	Diagnosis and classification	Operation	Date	Condition on evacuation	Remarks

GENERAL REMARKS CONCERNING CRANIOCEREBRAL WOUNDS

Every scalp wound, no matter how trifling, is a potential penetrating wound of the skull. Many penetrating wounds are met with even among the walking wounded. Only after an X-ray, after shaving the head, and possibly only after exploration, can one be assured that there is or is not a cranial fracture with or without dural penetration.

If a case is operated upon and a penetration found, the operation must be completed, with a primary closure following the special debridement applicable to these injuries. In this respect wounds of the nervous system differ from other wounds which in times of rush should not be subjected to primary wound closure. "All or nothing" is a good rule to apply to craniocerebral injuries—in short, evacuate these cases untreated to the nearest base (except for shaving and the application of a wet antiseptic dressing) rather than do incomplete operations. Patients with craniocerebral injuries stand transportation well before operation; badly during the first few days after operation. This is true of all primary wound closures.

Cranial cases in more or less shock need not undergo a period of resuscitation. The operations should be done under local anesthesia combined with morphine. Consequently the patient can be properly warmed and given fluids during the course of the operation through which they will often sleep. Only in exceptional cases, when patients are irrational or uncooperative, is a general anesthetic necessary. Its administration always adds to the difficulty of the operation, and by increasing intracranial pressure causes extrusion of brain and tends to increase the damage already done.

The chief source of the high mortality in cranial wounds is infection—infection of the meninges; direct infection of the brain leading to encephalitis; infection of the ventricles. Wounds in which the dura has been penetrated are supposed to give a mortality of from 50 to 60 per cent, due to infection. It, however, has been shown that experienced neurosurgical surgeons can lower this supposedly inevitable mortality to 25 per cent if the operations can be done with reasonable promptitude in a forward area and the cases retained for a reasonable time after operation. These figures are capable of still further improvement.

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CLASSIFICATION OF HEAD WOUNDS

On the basis of their severity, gauged by mortality percentage, head wounds may be divided into the following categories:

I.	Wounds of the scalp	Mortality circa 5 per cent.
II.	Cranial fractures without dural penetration	Mortality circa 10 per cent.
III.	Cranial fractures with depression and dural penetration, but without extrusion of brain	Mortality circa 20 per cent.
IV.	Wounds usually of gutter type, with brain extruding and indriven bone fragments	Mortality circa 30 per cent.
V.	Wounds usually of penetrating type with indriven bone fragments plus metal	Mortality circa 40 per cent.
VI.	Wounds of Type IV and V with penetration of bone or metal opening ventricles	Mortality circa 50 per cent.
VII.	Craniofacial wounds of orbitofrontal or temporopetrosal type in which ethmoid or petrosal sinuses are opened. Primary closure impossible and risk of secondary infection great	Mortality circa 60 per cent.
VIII.	Perforating or transversing wounds	Mortality circa 70 per cent.
IX.	Extensive bursting fractures. (Fatality very usually due to trauma rather than infection.)	

CLINICAL RECORDS

A preliminary note with (1) a brief history of case, (2) the patient's general condition, (3) the characteristics of wound, and (4) the positive neurological findings, should be made before the patient becomes drowsy from his morphia, which may well be given an hour before the operation and before the act of shaving.

DUPLICATING BOOKS

These are timesaving and desirable, for not only is it essential that the surgeon retain a record of his own cases and keep track of his end results, but it is of great importance that a duplicate record be forwarded in the field envelope with the patient, so that subsequent attendants may know something definite as to the patient's condition and the procedure followed in the forward area.

INFORMATION POST CARDS

Ordinary plain French post cards requesting information as to the outcome of the operating may be inclosed in the field envelope, addressed either to the surgeon himself, or to the senior consultant in neurological surgery, A. P. O. 731, who will forward the report together with such other information as may be pertinent.

PREPARATION FOR OPERATION

The success of these specialized operations and the celerity with which they may be done depends entirely on attention to detail and development of team play. Don't hesitate to do the first case or two slowly and carefully. Time will be saved on succeeding ones.

As the preliminaries may take almost as long as the operation itself, two tables should be in use, or if not two tables, the patient being prepared should be on a stretcher and trestles alongside the tables on which one operation is being completed.

Morphia is well tolerated. A third of a grain should be given and this repeated if necessary.

After a thorough soaping, with massage to soften the hair matted by blood, the entire head should be shaved, an act which requires no inconsiderable skill and on the perfection of which the successful outcome of the operation depends not a little. A shaving brush is essential to a good lather. The hair should not be clipped as this greatly increases the difficulty of shaving.

Novocainization of the scalp.—The infiltration should be made in lines of the proposed incisions 15 to 20 minutes before the patient is put on the table for operation. After novocainization it will be found that the dirty wound may then be filled with gauze before the final cleaning. This need consist of nothing more than careful wiping of the scalp with alcohol followed by bichloride solution. Avoid the use of iodine, picric acid, etc.

Position of the head.—Ordinary pillows and long sandbags are desirable. In order to get a proper elevation of the head so that it can stand free of the surroundings, one or two loosely filled sandbags, measuring about 8 by 8 by 3 inches, covered with rubber sheeting, will be found convenient.

A secure arrangement of towels to prevent their slipping in the course of a prolonged operation is essential, and it is well to have some sort of makeshift wire rack to keep the towels from settling against the patient's face.

A head-light is desirable, since the lighting system over most operating tables is central with imperfect illumination of the end of the table.

THE OPERATION

Its principles are those of wound débridement in general, consisting in the removal of the contaminated margins of the wound and tract, together with soiled fragments of indriven bone, and, if possible, of the foreign body.

It is unnecessary to remove more than the merest edge of the contused scalp wound. It is found that the making of "tripod incisions," which radiate from the central wound, permits of the reflection of three flaps, which when undermined can subsequently be drawn together with complete wound closure. Sufficient exposure of the cranial lesion is secured by these reflected flaps. Only in the case of large scalp defects is the switching of flaps necessary for closure and it is questionable if this is ever desirable.

The bone defect should be closely encircled by three or four perforations with perforator and burr, and these openings connected by linear cutting forceps (Montenovesi preferable, small De Vilbiss can be used). In this way the bone defect can be excised in toto and in the majority of cases the entire block may be tilted up in one piece. Some bone wax should be at hand. Nibbling with rongeurs across the area of the bone defect after preliminary lateral trephining is undesirable, particularly as this is apt to be a soiled area. Leave as small a bone defect as possible—a quarter of an inch margin beyond the defect suffices.

Do not enlarge the area of dural laceration. Never open an intact dura unless (1) an underlying clot or area of pulped brain is indubitable; (2) the operation is sufficiently early to antedate infection of the internal wound; (3) you have the experience and materials for an accurate reclosure. Except in very skillful hands a dural incision greatly increases the chances of a fatality from infection. In the British Expeditionary Forces there are strict regulations against it under any circumstances whatsoever. Curved French round-pointed needles with fine black silk sutures are essential for proper reclosure of the dura in case it has been opened during the operation.

The débridement of the contused area of the brain and tract can be best carried out with production of the least damage to the brain by gentle suction and irrigation with a soft catheter to which a Carrel syringe with a rubber bulb is attached. The catheter detects indriven bone fragments as well as does the finger, and they can be picked out by delicate esquillectomy forceps. Metallic fragments of small size are surprisingly well tolerated. It is therefore much better to give the patient the chance of carrying the missile, which may not have been contaminated, than the certainty of having existent paralysis increased and perpetuated by too energetic attempts to extract it when deeply placed. When at hand, a magnet will be found useful as a means of extracting shell fragments from the bottom o a tract.

A craniocerebral wound should never be sponged with dry gauze. Pledgets of cotton wrung out of salt solution will clean the wound infinitely better and will be much less likely to start up bleeding. All sponging, whether by operator or assistant, can be done by such pledgets held by the forceps, thus keeping fingers from the wound.

Bleeding points from sinuses or brain should be checked by tissue implantation. "Stamps" of muscle are most efficacious and can usually be obtained from some other operation or by additional incision from the patient himself.

ARMAMENTARIUM

In addition to the usual dissecting set with rongeurs, etc., a proper layout of instruments should include:

Perforator and burr.—The burr in the official brain, plastic, and oral surgery set is much too small and is therefore somewhat dangerous. Care must be exercised in making an opening which will be sufficiently large to introduce the cutting forceps.

The cranial cutting forceps in the official sets are of the De Vilbiss pattern with two blades, the smaller of which can, with care, be introduced through the small opening without damage to the dura, and the three or four perforations encircling the bone defect can thus be connected.

The Carrel syringe utilized for suction is of the common type of glass syringe in general use. The catheter should be very soft and should have a large bore with the eye near the end.

Delicate esquillectomy forceps for the removal of bone fragments after they have been detected by the catheter are desirable.

Antiseptics.—In an early operation, in which thorough cleansing of contaminated tissue is possible to the depth of the wound, no antiseptic need be employed. In many craniocerebral wounds, however, it is often impossible to be sure when, by thorough suction, the pulped and contaminated brain from the depth of the tract has been completely removed, and there is a temptation to lean, therefore, upon the crutch of an antiseptic. Oily solutions are preferable, and Dakin's dichloramine-T in oils, which has a prolonged antiseptic action, is not only harmless to the tissues but appears to be the most suitable antiseptic to bury in these cases. Through the catheter, after the tract has been as thoroughly cleansed as possible, a cubic centimeter or so of dichloramine-T may be introduced as the catheter for the last time is withdrawn.

Dressings.—In wounds of the head, particularly if the brain is exposed and the defect can not be closed, gauze should not be placed directly against the wound. The best substance to interpose between the wound and the gauze dressing is gutta-percha tissue which has been practically unobtainable. A fairly good substitute for this is cellulose tissue. This material can be boiled and therefore in the individual cases can be used again for subsequent dressings. It can also be used most advantageously for drains in case they are needed.

One difficulty which is met with by those inexperienced in cranial operations lies in the application of a dressing which will remain in place. Many of these patients are restless and pick at their bandages, which become easily dislodged. In most hospitals will be found bandages which have been cut on the bias. With practice these bandages can be adjusted to fit the head snugly, and can be brought around under the chin without annoying the patient too greatly. It is usually necessary to place several safety pins in the areas where the turns of the bandage cross. A neat head dressing is usually a good indication of the quality of the operation which it conceals.

APPENDIX

Supplies.—Duplicating books and certain other supplies may be obtained from the senior consultant in neurological surgery, A. P. O. 731.

From Gentile, 49 Rue St. André-des-Arts, Paris, esquillectomy forceps, an excellent perforator and burr, curved French needles, Carrel syringes, and catheters.

From Intermediate Medical Supply Depot No. 3, A. P. O. 737, by requisition through any commanding officer, Lurken's sterile bone wax, head lamp, cellulose tissue, and dichloramine-T with paraffin and eucalyptus oil. Also Lilly capsules and various novocain preparations. The most convenient are the 1-ounce bottles of powdered novocain of the Saccharin Corporation (Ltd.). To make a 1 per cent solution add 0.3 grams of this powder to 30 c. c. of sterile water. To this 30 c. c. of 1 per cent solution add 15 drops of adrenalin. This will make the scalp incisions comparatively bloodless. The Lilly No. 1 gelatine capsules which come in boxes of 100, hold just 0.3 grams of this powdered novocain. It is a convenience therefore to secure these capsules, as they can be filled without weighing out each separate portion of 0.3 grams. A Luer syringe and satisfactory needles can also be obtained from the medical stores.

CARE OF HEAD INJURIES AND INJURIES TO THE SPINE AND PERIPHERAL NERVES IN THE FORWARD HOSPITALS

HEAD INJURIES

The senior consultant in neurological surgery, A. E. F., had learned from personal experience in British casualty clearing stations and general hospitals that the accepted high mortality of the craniocerebral cases could be reduced fully 50 per cent if these cases were operated upon in forward areas. A series of about 200 patients operated upon in the fall of 1917 at a casualty clearing station of the British Expeditionary Force, which was given over entirely to wounds of the head, gave 28.5 per cent mortality; a similar series operated upon at a later period by members of the same team in an American base hospital attached to the British Expeditionary Force gave a mortality of about 45 per cent.

NEUROSURGICAL TEAMS

Certain difficulties, never entirely overcome, were met with in the organization of the neurosurgical teams. It was obvious that if surgeons were to be assigned to forward hospitals in charge of teams that they should primarily be good general surgeons, for their presence would be an encumbrance if they could only cover their specialty. This had one unfortunate outcome, for during the months of June and July eight of these specially equipped officers were soon put in surgical charge of their hospitals and became triage officers, so that their services as neurosurgical experts were lost. Another difficulty lay in the administration opposition to the performance of operations of a time-consuming and detailed character, particularly during periods of rush. As these operations should be done under local anesthesia, they necessarily consume time, and rarely could more than eight serious head wounds be thoroughly done by one team in a working day. Where there was a large number of wounded, the temptation was strong for hospitals to strive for an operative record, and teams were apt to be rated by the commanding officer according to the number of cases they were able to cover in their individual shift. As a result, in many hospitals the neurosurgical teams were restricted to general operations and the more tedious head cases were either passed on to the base or were distributed without selection among the teams on duty, who did incomplete operations.[c]

During the early operations in which some of our forces were engaged in the latter part of June, only two teams had been organized, one at Mobile Hospital No. 2 and another at Mobile Hospital No. 1. A subsequent survey of the head cases which had reached the Paris area and the centers of the intermediate zone at Bazoilles and Vittel showed that practically no case of penetrating wound of the head had survived except the 10 or 20 who had gone through the hands of these two teams.

By July, 1918, it had become possible to apportion to most of the evacuation and mobile hospitals of the forward area one team which had had more or less personal instruction and which had been equipped with the proper sur-

[c] To give an idea of the importance of having men for this special work, the operative mortality in a series of 38 cases of dural penetration of one neurosurgical team working at a mobile hospital was 29.4 per cent, whereas in 26 cases done by 11 different surgeons without equipment or training in the same hospital it was 62 per cent.

gical supplies. This was due to the fact that some medical officers who had received some neurological instruction in schools established for this purpose at home had arrived recently in France. Also a number of sets of instruments for brain surgery had been sent out and had become available. Each of the neurological teams was furnished with the instructions quoted above.

Before the St. Mihiel offensive, September, 1918, more time for preparation was given, and each hospital was supplied with one neurosurgical team which had had some experience. Even though this operation was of brief duration, it became apparent that one team in each hospital was not sufficient to screen out the cases, for though the work was covered in some hospitals, in others the neurosurgical team was either off duty or busy doing general surgical work so that most of the head cases were handled by the general surgical teams rather than have them wait. In consequence, more craniocerebral cases had been operated upon, it was found, by inexperienced than by experienced teams and the hospital mortality was very high—considerably over 50 per cent, exclusive of the cases which subsequently succumbed in base hospitals.

In view of this experience and in preparation for the Meuse-Argonne operation, the proposal was made to the representative of the chief surgeon, First Army, that at least two neurosurgical teams be supplied to the hospitals which were on the main avenues of evacuation, viz., at Fleury, at Souilly, and at Villers-Daucourt, with the issuance of orders to field hospitals to route cases direct to one of these points. This plan was met with a counterproposal that we should attempt, as the British had done, to have a special hospital somewhat more in the rear to which all head cases could be forwarded. A hospital at Deuxnouds was selected for this purpose by the representative of the chief surgeon, First Army, and several neurological teams were concentrated there. Between September 29 and October 16, when the hospital was in operation 813 cases were secondarily routed there. The situation presented difficulties. Although it seemed an easy matter to have all wounded men wearing head bandages collected at one point, since this point was farther away than the main hospital centers the cases were almost certain to be dropped at these centers, necessitating a delay of from 10 to 12 hours before they could again be sorted and ambulances secured to forward them to the so-called head center. However, this center was placed in a town far from a railhead, so that the hospital became overcrowded and evacuation was difficult. Lastly, the mistake was made which perhaps was unavoidable, of using the personnel and equipment of a mobile hospital unit, which was withdrawn after a 10-days' service, leaving no one to carry on the work in the interval until another mobile hospital unit was similarly and temporarily utilized.

In spite of these difficulties, however, the hospital did creditable work and under different circumstances could have relieved to a greater degree the pressure on the evacuation hospital a few miles farther forward.

In preparation for the later phases of the Meuse-Argonne operation, the earlier proposal to assign neurosurgical teams to the forward hospital was accepted by the general staff, and at Evacuation Hospital No. 7 at Souilly, at Hospital No. 114 at Fleury, at A. R. C. Hospital No. 110 at Villers-Daucourt, a sufficient number of teams to operate continuously on craniocerebral injuries

were stationed. This implied the setting aside of 50 to 100 beds for the retention of these cases—not a particularly large number of beds, in view of the size of these hospitals.[d] The work according to this arrangement was very much more satisfactorily accomplished than at any time previously in spite of the fact that with the advancing line an increasingly long interval elapsed between the time of injury and the time of operation.

In summary.—So far as these craniocerebral wounds were concerned, experience may be compared profitably with each of the following plans: (1) Operations on craniocerebral wounds by uninstructed surgeons, unfamiliar with this special kind of work; (2) single neurosurgical teams placed in individual hospitals; (3) a number of teams collected in one special hospital for head wounds, after the principle adopted in the British Army; (4) the placing of two teams in the larger evacuation hospital centers on the main lines of traffic.

Of these four plans undoubtedly the third is suitable for a more or less stationary battle front such as existed in Flanders during 1917. Plan 4 was unquestionably the more desirable under such conditions as existed in our Army during the Meuse-Argonne operation. Supplementary to this arrangement it would have been ideal to have the convalescent cases sent directly to a neurological center in the base.

SPINAL CASES

These did very badly throughout, as was anticipated. Most of them were immediately evacuated to base hospitals and fully 80 per cent died in the first few weeks in consequence of infection from bed sores and catheterization. The conditions were such, owing to pressure of work, as to make it almost impossible to give these unfortunate men the care their condition required. No water beds were available, and each case demands the almost undivided attention of a nurse trained in the care of paralytics. Only those cases survived in which the spinal lesion was a partial one.

PERIPHERAL NERVE CASES

It was impossible, owing to the conditions in the forward hospitals and pressure of the work, to do more than emphasize the necessity of some neurological observations being made before any major operation in the nature of a débridement was carried out for wounds of the extremities. Experience had shown that excision of presumed contaminated tissues in the depth of the wound had not infrequently led to accidental nerve division.

It was urged, furthermore, whenever the preliminary examination showed the nerve to be injured, that if possible it should be exposed in the wound, its condition noted, and in case of traumatic division a suture be immediately performed. There can be no question that immediate suture of divided nerves, with primary wound closure, offers the best chance of restored function. However, in view of the regulation against primary wound closure during the active fighting of the summer and fall of 1918, it was practically impossible, except in isolated cases, to attempt the early suture of nerves.

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[d] It may be noted that a *sine qua non* of these operations is a primary wound closure after thorough wound débridement, owing to the certainty otherwise of the development of a cerebral fungus. Hence the regulation forbidding primary wound closure in the forward areas was, in cases of this kind, necessarily overridden. It is this fact which made it obligatory that patients thus operated upon should be retained for a period of at least 10 to 14 days.

CARE OF HEAD INJURIES AND INJURIES OF THE SPINE AND PERIPHERAL NERVES IN BASE HOSPITALS

NEUROLOGICAL CENTERS

Within hospital centers.—The commanding officers of the various hospital groups were requested to sort at the railhead, as far as possible, and to send to a selected hospital in the area as many of the cranial cases as possible, and subsequently to secondarily transfer to this same hospital the peripheral nerve cases. It was the intention to have a nucleus of well-trained neurologists and neurosurgeons for each of the larger hospital centers, and in some areas notably in the Bazoilles group, and at Vittel and Contrexeville, this plan was put in operation. Likewise Military Hospital No. 1 served as a neurological depository for the Paris group.

A special hospital.—Owing to lack of competent personnel and to the difficulties and inconveniences of secondary routing, the project of having one or more actual neurological centers comparable to the French centers, was not put into operation, though after the arrival of Base Hospital No. 115 at Vichy a very promising start was made there in this direction.

CHAPTER II

ACTIVITIES OF THE AMERICAN FIRST ARMY HOSPITAL AT DEUXNOUDS [a]

On September 26, 1918, Casual Team No. 538 was ordered to proceed to Deuxnouds and to take over the French ambulance in that village, it being the intention of the chief surgeon, First Army, to convert this ambulance into a head hospital.

At noon of the 28th the first portion of the equipment of Mobile Hospital No. 6 arrived and continued to do so during the 29th and 30th. Because of the haste in opening, the taking over of the French hospital, and the functioning for the first time of a mobile unit fresh from its assembling point, many improvisations were necessary, and as complete records as might be desirable were not at all times obtained, especially in the first few days.

In the triage all lightly wounded were dressed and such as were nonoperative immediately marked for evacuation. Operative cases were undressed, bathed, and placed on stretchers pending operation. About 90 per cent of the neurosurgical work was done during the first two weeks.

Inasmuch as no systems of permanent records in evacuation hospitals had been established, it was necessary to improvise some method of keeping track of at least the most important cases received at this hospital. Each team was asked to keep a record in a duplicating book provided for them, of which one copy was placed with the field medical card or its equivalent. When a patient was evacuated, the records were passed through the office of the surgical chief, who abstracted the more essential points upon the patient's field medical card and saved the complete record to turn into the consulting surgeon's office. Unfortunately, when teams were ordered away, records were left in the hands of men who, although able and willing, had had no experience previously with the system of keeping them.

The total number of admissions up to the morning of October 15 was 815. Of these, 403 underwent operation, leaving 412 which were dressed in the triage at once and marked for evacuation. These cases then had passed through, in the majority of instances, triage at the field hospitals and evacuation hospitals without their dressings being changed and had come through to Deuxnouds before being recognized as nonoperable and evacuated. Of the 403 operations, 106 were craniotomies.

The operative capacity of the Deuxnouds hospital was, roughly, 100 cases per 24 hours, of which, from the experience gained there, one would expect 25 to be craniotomies and 15 dural penetrations. In addition, on the above basis, 100 cases would be passed through the triage with a dressing and for immediate evacuation. If, as is generally estimated, 10 per cent of the total casual-

[a] Based on report on head hospital at Deuxnouds, undated, made by Capt. S. C. Harvey, M. C., to the chief surgeon, A. E. F. Copy on file, Historical Division, S. G. O.

ties involve the head, face, and neck, then this hospital was caring for its proportion of 2,000 casualties in 24 hours.

With the equipment the personnel could be expanded at least 50 per cent, and in that case such a unit could handle 200 operations, admit 400 casualties, and handle its proportion of 4,000 in the 24 hours. This would make a total of 28,000 a week or, roughly, 100,000 a month, which perhaps is approximately the casualty rate for the fighting at this time in the First Army; that is to say, one well-developed unit of this type or two smaller ones should be able to handle wounds above the clavicle for one army as at present organized.

Frequently it is assumed that the retention of head cases will soon choke the bed capacity of a hospital. The normal intakes of this hospital estimated at 15 dural penetrations per day (these being the only cases retained) would provide at the maximum an accumulation of 100 per week. In two weeks this type of case is evacuated, so that at no time would more than 2,000 beds be occupied.

As a matter of experience, during the second week of function of this hospital, the beds occupied reached 290, but this was chiefly because of lack of evacuation, and in spite of this there was no choking of the hospital by retention of head cases.

CLINICAL DATA

Deaths.—In so far as neurosurgical conditions are concerned, the deaths from the opening of the hospital until its evacuation by Mobile Hospital No. 8, that is until about November 8, numbered 67, of which 25 died without operation and 42 following operation. These have been classified according to Cushing's classification, as follows:

DEATHS UNOPERATED

Cranial: Group I (general shock and sepsis from other wounds)	1
II (previously operated)	1
IV (previously operated)	1
V (all moribund on entrance)	5
VI (4 meningitis; 3 moribund on entrance)	7
Wounds of head (no data; moribund on entrance)	4
Dead on entrance (dural penetration; no further data)	1
Spinal cord	1
Total	21

Of these, it may be noted that two (Group II and Group IV, respectively) previously had undergone operation. The records of these are as follows:

CASE 1.—A. I. J. F., No. 3270146. Wounded October 5, 1918. Field hospital (?). Copy of note: "(1) G. S. W. left arm; compound fracture. (2) G. S. W. head, left. Compound fracture of skull. 36 hours. Operation October 7: Cleaning, partial suture of scalp; no evidence of depression of skull. Amputation left arm after consultation. Hold." Entered Mobile Hospital No. 6, October 12. Amputation left forearm. Suture lacerated scalp wound, left occipital. Neurological examination negative; X ray negative. Dressing. One suture removed from scalp. Patient profoundly unconscious; manifestly moribund. Died October 13. Autopsy: Depressed fracture of the inner plate, left occipitoparietal, with large extradural hemorrhage; no dural penetration. Brain saved for section.

This patient arrived profoundly unconscious, with notes of operation performed elsewhere and revealing no fracture. A negative X-ray and neurological examination of the patient confused the picture still further. In view of the moribund condition of the patient and the negative findings, it was not thought worth while to do an exploration. The surgeon who operated upon him would have been in a better position to judge of his condition and the advisability of further operative action. Consequently this case should not have been evacuated.

CASE 2.—J. G., No. 1624243. 79th Div. 314th Machine Gun Battery, B Co., admitted to A. R. C. Hospital No. 114 with following note: "X-ray: F. B. 1 cm. right side of head, 4 cm. under skin mark, right temple. Large depressed fracture of skull; left parietal region. 22 hours after injury. Operation: Removal of depressed parts of bone. Brain irrigated and macerated brain tissue removed. F. B. not removed. Hold." Admitted to Mobile Hospital No. 6, October 6, 1918, 11.30 p. m. A. T. S. given. October 7: Unconscious; delirious; tosses about with left arm and hand. Incontinence of feces and urine. Complete right-sided hemiplegia. Right facial palsy. Large postoperative wound, left parietal region; crow-foot incision; sutures infected; spinal fluid oozing out. Three central sutures removed. Skin edges infected; decompressed area size of half dollar in left parietal; there has been considerable brain injury. No rigidity of neck; no Kernig; left Babinski plus. October 8, 1918. Considerable foul discharge. Neck rigidity marked. October 9, 1918. Meningitis. Foul discharge from wound; opened more; fragments of inner table which were loose, removed. October 10, 1918. Died 12.40 p. m. No autopsy.

It is impossible to convey by notes, especially such as can be placed on a field card, the completeness of an operation and the history of a case such as this. Any dural penetrations should always stay under the care of the man operating until either evacuated to the base or dead.

Of the five cases in Group V dying without operation, in three the foreign body had traversed or lodged in the region of the basal ganglia. In the remaining two the cranial damage was extensive, partly direct laceration of brain tissue and partly extensive "commotion" of the brain, such as is seen in profound concussion. They were all moribund on entrance. The following case is typical of this group:

CASE 3.—W. H., Pvt., No. 542269, 7th Inf., Co. H. Field Hospital No. 27, October 8, 1918. G. S. W. skull. Field Hospital No. 26, October 8, redressed, morphia, external heat, small piece of high explosive taken from right knee. Wound of thigh dressed. Mobile Hospital No. 6, October 8. Patient entered hospital in unconscious condition. No history other than above. Pulse 144; respiration rapid and with apparent beginning edema of lung. Wound: G. S. W. right anterior quadrant skull, about 4 cm. in length. Multiple G. S. W. right leg. X ray; foreign body 1 by 1½ cm. inside skull, 7½ cm. under skin mark right anterior frontal region head on left side; 8 cm. under skin mark on middle anterior frontal region; plane passing on the line drawn will meet at a point giving the position of foreign body 1 by 1½ cm., 6 cm. under skin mark on upper inner surface of thigh, right. Foreign body $\frac{3}{16}$ by $\frac{4}{16}$ under skin mark on point of heel, right. October 9, 4.15 a. m. patient died. Autopsy: Penetrating wound right frontoparietal region. Extensive comminution of cerebrum with softening opposite side. Brain saved for section.

In Group VI, three patients entered in a moribund condition, the missile having, judging from its course, reached or traversed the ventricle. Four died of meningitis, one having a foreign body traversing the lateral horn of the left ventricle, unconscious on entering and developing infection in 24 hours; a second entering, unconscious, with foreign body localized in such a position

as to indicate that it had traversed the ventricle, developed signs of meningitis in 24 hours and died on the seventh day after admission; a third had outspoken signs of meningitis; and the fourth, the foreign body had traversed one hemisphere from pole to pole, passing through the ventricle, while the man was profoundly unconscious and developed meningitis in 24 hours. A typical case is as follows:

Case 4.—145th Inf., Co. B, 37th Div. No notes from field hospital. Admitted to Mobile Hospital No. 6, September 30. Unconscious, with diagnosis of G. S. W., left parietal region. Condition good. Entrance wound in front of left ear just above zygoma. X ray: Foreign body ¼ by 1 cm. lying below mark on right ear, right side of head to the table. Neurological examination: Complete right hemiplegia. October 1, 4 p. m.: Temperature, 100.6; pulse, 94; deeply unconscious. Fundus examination: Disks blurred; fields distended. Operation not considered advisable. October 3: Symptoms of meningitis. October 4: Semiconscious. October 7: Semiconscious; marked symptoms of meningitis. October 8: Died from meningitis. October 9: Autopsy. Penetrating wound left temporal region, entering tip of temporal lobe, entrance measuring 2 cm. in diameter, exuding quantity of pus and disorganized brain. Acute purulent meningitis especially marked over the base.

DEATHS OPERATED

Operated deaths are as follows:

Cranial: Group II	1
III	2
IV	17
V	3
VI	5
VII	2
VIII	2
IX	2
Sinus (venous)	1
Total	35

The death in Group II was due to lobar pneumonia, shown at autopsy. There was also a linear fracture of the skull down to the right, but with no evidence of depression. A small and unimportant extradural clot was present. This fracture was not recognized at operation, and the skull consequently was not trephined.

The records of the patients in Group III who died are as follows:

Case 5.—G. H. P., No. 65331, 103d Inf., Co. H. Admitted to Mobile Hospital No. 8, October 25, 5 p. m. Wounded 7 a. m., October 24. A. T. S. given. Unconscious 15 to 20 minutes after accident, with immediate paralysis left side of body. G. S. W., 12 by 3 cm., right parietal region, dirty and inflamed. G. S. W. right arm and elbow, outer surface, above and below knee, foul-smelling discharge suggesting gas infection. X ray head: Penetrating skull, right parietal. Numerous foreign bodies ½ by ¾ cm. in length in wound in skull. One foreign body 1 cm. long projects from the wound, to inner surface of the skull. No foreign body in brain. Right arm, leg, and thigh negative. Neurological examination: Paralysis left side of face, left arm, and left leg. Loss of sensation to touch and pin prick left arm and hand. Touch sensation in left hand present. Deep reflexes left arm, left leg hyperactive. Left epigastric, left cremasteric absent; right present. Spasticity left leg and left arm. Left Babinski. Pulse rate 100. October 25, 10.20 p. m.: Blood pressure, systolic 120, diastolic 80. Operation: Excision of scalp. Block removal decompressed skull fracture 3 cm. in diameter; dural penetration. Subdural blood clot and contused brain

removed by suction. Dural wound left open. Partial closure of scalp. Local anesthesia, under primary ether. Arm and leg wounds excised for drainage. Pulse 150 and very weak, so that more extensive procedure could not be done. October 26, 8.45 a. m.: Convulsion, Jacksonian type, left side of face, left hand, duration 10 minutes. Dressings changed. Pulse 120. During the next 12 hours, patient had 6 of the localized convulsions. October 30: Continued and increasingly severe convulsions since operation, always involving left arm and left side of face. Left leg paralyzed; leg wound dirty and foul-smelling. General condition never good and became steadily worse. Right leg shows evidence of gas infection. Died at 7.30 p. m.

The severe shock and the sepsis resulting from wounds other than that of the skull seemed to preclude as extensive an operative procedure as was advisable in the first place, and also a secondary exploration to ascertain the cause of the irritative phenomena, which might otherwise have been done. A similar case with Jacksonian attacks, on secondary operation showed a tract in the cortex about 2 cm. deep under considerable pressure and tension. On relief of this, the convulsion subsided. No autopsy.

Case 6.—H. P., No. 2257218, 361st Inf., Co. C, Pvt. Admitted to Mobile Hospital No. 6, October 4, 1918. Wounded October 3, 3 p. m. Was not rendered unconscious and was able to walk. X-ray examination: Foreign body 8 by 5 cm., 20 mm. from mark on posterior surface of right thigh. Forehead shows no foreign body. Wound of head 3 cm. above right eyebrow, 1 cm. in diameter. Neurological examination: Right pupil greater than left; pupils react to light, otherwise negative. Operation: October 4, 5.50 p. m. Block excision of block and bone. Internal plate, 2 by 1½ cm., which had been driven inward and striking into dura, removed. Escape of large amount of clear, cerebrospinal fluid. No contusion of underlying brain noted. Dura and scalp closed with silk. October 7: Scalp wound infected; opened. October 8: Kernig positive. Neck stiff; lumbar puncture done, 20 c. c. cloudy fluid removed. October 9: Lumbar puncture, with removal of cloudy fluid. October 10: At midnight patient died of meningitis. Autopsy: Scalp wound only slightly infected. Dura tight. Spreading from this is an acute, purulent meningitis, most marked over the right cerebrum and base.

In Group IV, there were 17 deaths, of which 1 had signs of meningitis on admission; 1 died of severe and generalized gas burns; 3 of meningitis; 8 encephalitis; and 4 directly as a result of very extensive intracranial damage, although this in some cases may have been complicated by infection. In other words, 11 out of the 17 cases were amenable to operative treatment.

In the cases of meningitis, two showed signs in 24 hours, making it seem possible that the meninges were infected previous to operation, while the third flared up on the fifth day following a very extensive herniation and encephalitis. In the first two, the scalp was closed tightly and not opened at any time. The third was left open because of the size of the scalp defect.

Four of the eight cases classified as dying of encephalitis had such an extensive intracranial damage that their condition was obviously practically hopeless for operation. One of these died of a gas infection of the brain.

The following is a typical case:

Case 7.—M. K., Pvt., No. 1630902, 30th Inf., Co. I. Evacuation Hospital (A. R. C.) No. 114, October 11. G. S. W. head. Admitted to Mobile Hospital No. 6, October 12, A. T. S. given. History: G. S. W. head, October 11, 4 p. m. Conscious, no vomiting. Paralysis, left; spastic. Condition fair. Wound 2½ by 6 cm., right parietal, parallel with sagittal suture to the right of mid line over parietal region. Ragged, dirty, depressed fragment 1 by ½ cm. Stellate fracture radiating from depression. X-ray examination: No

foreign body. Fracture of skull through inner table beneath wound. Neurological examination: Spastic left hemiplegia, arm and face; arm less than lower limb. Knee jerks diminished, left. Ankle-clonus, left. Operation: Débridement, two sutures in the dura; closure with no drainage. October 13: Wound dressed; considerable discharge. Patient stuporous. October 14: Wound shown increasing sanguino-purulent discharge. No rigidity marked. Unconscious. October 15: Condition serious. Much foul discharge from wound. Unconscious; no rigidity; Kernig. October 16: Nystagmus to the left. Condition worse. Convulsion this morning at 9; this afternoon at 1.30. Died at 5.30 p. m. Autopsy, October, 17: Wound, vertex, of the skull, right parietal region, softened brain substance exuding. Three radiating lines of fracture from bone defect. Opening in the dura measures 3 by 5 cm. Brain is so softened that its removal intact is almost impossible. Right parietal lobe entirely replaced by softened hemorrhagic mass.

The remaining four cases represent errors of treatment, and these are reported in detail:

Case 8.—F. S., Pvt., No. 2965964, 314th F. A., Co. E. Wounded October 7, 1918. French field hospital, October 7, 1918. A. T. S. given. G. S. W. head. Entered Mobile Hospital No. 6, October 7, midnight. History indefinite; patient's statements uncontrolled and unreliable. Given his name, organization, State, etc., but readily forgets and repeats. Recognizes objects and names; knows he is in hospital and has been wounded. Wound: Small penetrating, left posterio-parietal, measuring 2½ by 1¼ cm. X-ray examination negative, for foreign body. Area of increased density size of nickel, suggestive of intracranial hemorrhage under wound. Operation: Débridement of scalp; fractured bone 6 by 5 cm. had been driven into the dura and brain. Removal of bone fragments, enlarging the opening to the size of a dollar, under local anesthesia. October 10: Visual fields somewhat limited, homonomously to the right. October 11: Patient much more alert. Visual fields probably normal. October 17: Sutures removed. Slight amount of sero-purulent material. October 24: Died at 7.15 p. m. Progressive cerebral herniation and signs of encephalitis.

The condition of this patient previous to the operation seemed quite favorable, but for some unknown reason the block operation with wide exposure was not done, consequently thorough débridement was not accomplished. Infection ensued in the presence of inadequate drainage, followed by progressive encephalitis and death.

Case 9.—F. D., No. 2557608, 138th Reg. Admitted to Mobile Hospital No. 6 September 30, 1918. Unable to talk. Slip with him says wounded in action: Day not known. Marked S. W. of skull. Condition: Unconscious on admission. An hour later could be roused. Could not speak, but some attempts to obey simple orders, such as moving arm and leg. Wound: Severe, penetrating, over left parietal region. Bone fragments driven inwards and down outwards. Neurological examination: Complete right hemiplegia. Right pupil larger than left. Right ankle-clonus. Right knee jerks greater than left. No Babinski. X-ray findings negative. Operation: Débridement; removal of shattered bone. No foreign body. October 2: Dressing, some herniation. October 3: Dressing; herniation increased; slight hemorrhage. October 4: Severe hemorrhage. Herniation of almost entire left lobe. Discharge of bloody spinal fluid on slightest cough. Died at 1.30 p. m., October 4.

Case 10.—Pvt. No. 1781329, Co. L, 313th Inf. Wounded, October 1, 1918. G. S. W. head: (1) fronto-parietal; no foreign body or fracture. (2) G. S. W. 5 cm. in length, left Rolandic area; indriven bone. Admitted to Mobile Hospital No. 6 October 2, 1918. Neurological examination: Spastic paralysis right side. Right facial paralysis. Operation: Débridement. No foreign body found. Subdural clots. Bone fragments removed. Closure incomplete. October 3: Slight hemorrhage from dural vessels; brain hernia. Vessel cauterized; actual cautery. October 4: Patient died, 5.45 a. m.

In both of these cases, the dressings were carelessly done, with compression and damage to the herniating cerebral tissue, followed by hemorrhage. This was controlled only after further rough usage, resulting in the shutting

off of blood supply to considerable areas of herniating cerebrum. Such a condition so handled is, of course, always progressive and followed by death.

Case 11.—F. C., Sgt. No. 2307026, Co. G, 127th Inf. G. S. W. head. Wounded October 4, 4.30 p. m. Hit by piece of high explosive. Unconscious for hour and a half. Vomited directly on regaining consciousness, but not since. At Field Hospital No. 27. A. T. S. given. Entered Mobile Hospital No. 6 October 6, 1918, midnight. Wound: Gutter wound over right median frontal, apparently tangential. Dirty and protruding cranial tissue. General condition good. Pulse 60. Weakness of arm and hand. Positive Babinski, left; cremasteric, left; less than right. No other signs. Operation: Wound in bone removed en bloc. Three bone fragments removed, completing half mosaic. Cortical bleeding started by an attempt to remove bone fragment; controlled by cotton and finally by a small facial slip. Scalp sutured. October 6, 3.10 p. m.: Left lower fascialis weak. Pupils equal and react to light and accommodation. Left arm paralyzed except for very slight movement of forearm. Left leg very weak; no Babinski or Oppenheim. Reflexes: Knee jerks, left greater than right; no clonus. Vomiting. Wound dressed; blood under scalp expressed; seems clean. Pulse rapid. October 7: Neck stiff. Optic neuritis. Unconscious. Pulse 116. Temperature 100.6; respiration 30. October 8: Condition much worse this morning; complete left hemiplegia; stuporous. Died at 10.05 a. m.

The tearing of the deep cortical vessel, and the consequent hematoma along the tract, destroyed what small chance of recovery this patient had. Examination of wound post mortem showed a gas infection involving the greater part of the right frontal lobe, patient having died of a gas encephalitis.

In Group V, three cases died following operation. One of these entered with a foreign body 5 by 3 cm. in left parietal region and a herniation already present measuring 6 by 8 by 4 cm. Patient was unconscious and hemiplegic. An unsuccessful attempt at removal of foreign body was made. Wound was dressed; patient died within 48 hours.

The records of the remaining two cases are given in detail.

Case 12.—J. E., Pvt. No. 2256961, 361st Inf., Co. A. Wounded October 1, 1918. Entered Mobile Hospital No. 6, October 3, 1918, 10.45 a. m. Penetrating wound right occipital region. X-ray examination: Penetrating wound: Foreign body 1⅓ cm. in the brain. Mid line 7 cm. back of external auditory meatus. No localizing neurological signs. Operation: Block removal of fracture area through tripod incision. Foreign body lying about 8 cm. under the surface removed; several bone fragments also. Scalp closed tightly. October 5: Incontinence of urine; temperature 100° F.; no nausea or headache. Deep reflexes very sluggish; drowsy. Disorientated for time and place. Knows he was in 361st Inf., does not remember any circumstances of accident. October 7: Temperature ranged to 102° F. Patient vomiting to-day. Fungus formation, with broken-down wound. Scalp resutured, with anterior drain. October 8: Bloody discharge but wound holding. Opisthotonos; positive Kernig; patient has developed meningitis. October 9: Died at 7.40 a. m.

Case 13.—Pvt. No. 1458990, 152d Inf. G. S. W. head. Entered Mobile Hospital No. 61 October 1, 1918, 12.05 a. m. Extensive gutter wound of left side of head from above left orbit upward and outward to left external auditory meatus. No neurological signs except for motor aphasia.

Operation: Local anesthesia. Débridement: Removal of bone fragments and pieces of shrapnel from brain. Closed in layers. October 7: Lower end of wound incision opened. Brain irrigated with saline. Fungus cleaned away. Scalp wound sutured tightly. October 10: Wound suppurating; dressed daily and irrigated with sterile salt solution. Draining profusely. Condition fair. October 12: Redressed. Free drainage, with suppuration of wound. Condition improved. October 13: Redressed. Some improvement. Temperature normal. Draining freely. October 14: Redressed. Wound condition same; still draining freely. Temperature 102.6° F. Suspicious Kernig. No opisthotonos. October 16: Died 4.30 p. m.

These cases are of special interest because once having been sutured and having broken down, they were again closed over the hernia. The conception in the operator's mind of the condition being that it was a purely mechanical thing, it was not appreciated that while cranial herniation is due to increased intracranial pressure, this may be either the result of edema from mechanical disturbances, or, what is more important in war injuries, from infection. If the herniation is due to a purely mechanical cause, under proper dressing it will shortly subside even if the scalp is left open. If, however, it is due to infection, as in any other region of the body, the infected area must be adequately drained. Both of these cases, as might have been expected under the treatment used, did badly.

Of the five deaths in Group VI, three were instances where the projectiles traversed the entire hemisphere passing through the ventricle in its course. Such injury—according to Cushing's experience, confirmed by this data—results uniformly in death. In time of rush such cases should be marked inoperable. An instance of this class is the following:

Case 14.—E. W., Pvt. No. 1937561, 26th Inf., Co. G. G. S. W. right side of head, severe. Entered Mobile Hospital No. 6 October 11. History of being wounded October 9, 4.55 p. m. States that he was struck by shrapnel. Not unconscious. Helmet broken. Very severe headache, and nauseated. Left hand has been weak since injury. No speech difficulty. Wound: Right frontal region, just back of hair line. Brain substance oozing. X ray shows machine-gun bullet lying near junction of temporal and occipital lobes on the right. Neurological signs: Left facial weakness. Left arm and hand extremely weak; left leg somewhat so. Slight diminution of sensation left. No astereognosis: Complete left homonymous hemianopsia. Reflexes, biceps, more lively right than left. Knee jerks, present right, absent left. Few clonic jerks each side. Operation: Novocaine and morphia. Complete removal of fractured skull. Débridement of scalp and track; through irrigation. Foreign body, machine-gun bullet; removal of right hemisphere, location 4½ cm. from point just above right external auditory canal and about 9 cm. from the point of entrance in the right frontal lobe. Irrigated with sterile saline. Bone fragments removed; scalp sutured; patient's condition good. October 13: Dressed, wound clean. Temperature 101.4° F.; delirious; stiff neck and double Kernig. Left hemiplegia present. October 14: Died 2.15 a. m. Autopsy: Penetrating wound, deep, right frontal lobe. Brain saved for section.

The two remaining cases were instances of indriven bone fragments reaching the ventricle, and they died of meningitis. About one in four of such wounds recover and they are, therefore, distinctly operable.

In Group VII, two cases died, both having a wound involving the orbital contents, frontal sinus, and frontal lobe. The extensive mortality accompanying this type of injury suggests more radical measures, which were not undertaken in this hospital, namely, evisceration of the orbit and establishing wide and thorough drainage.

Two cases with traversing wounds of Group VIII died following operation, one of the cerebellum and one of an occipital lobe, the latter dying from a generalized gas infection, apparently arising from the foreign body which lodged deeply in the neck muscles and was not removed. In the former the foreign body traversed the right lobe of the cerebellum, almost completely destroying it, encephalitis of the cerebellum resulting in death in six days.

Two deaths are recorded in Group IX, one being the type of basal fracture commonly seen in civil life, and the other a fracture of the petrous portion of the temporal bone, with cerebrospinal fluid from the ear.

Of these cases involving a venous sinus, one died. In this case the approach was made with an inadequate exposure resulting in profuse hemorrhage, packing, and death on the fifth day, which, however, was probably due to the effect of the missile ranging forward and inward to the basal ganglia.

PATIENTS EVACUATED

The following records are of cases that were evacuated in good condition: Cranial—Group I, 69; Group II, 32; Group III, 14; Group IV, 6; Group V, 11; Group VI, 1; Group VII, 1; Group VIII, 2. Sinus (venous): 4. Total: 140.

CRANIAL

Group I.—The majority of cases in this group were scalp wounds in which the injury had extended to the bone. In a few, however, the pericranium was not lacerated. It would seem, particularly in times of rush, that the patients in whom the laceration did not extend to the bone might be evacuated without operation. It is realized that there might well be a depressed fracture underneath such a lesion, but with the absence of neurological symptoms and the lack of a tract leading from the external wound to the depressed fracture, there would be few if any cases which would afterward show either neurological signs or infection of the fracture and the underlying cranial structures. In other words, in proper hands, a more conservative position might be taken as regards the operating on scalp wounds.

Group II.—Every case of this group should be explored and trephined. Experience with this hospital confirmed what already was well known, that is, that even the simplest linear fracture or even abrasion of the skull may overlie serious intracranial damage. If the pathway from the external wound to the fracture is continuous, then infection will in many cases—even with the simple depressed fracture without dural penetration—lead to a meningitis or an abscess in the contused adjacent cortex.

Group III.—The majority of cases reported in this group showed only a small puncture of the dura or slight laceration. An occasional one, however, had a short tract of contused tissue. The question always arises as to whether the best procedure is to close the dura at once with silk sutures, thus hoping to avoid infection of the underlying tissues, or to leave it open, arranging for drainage. From a study of the cases in this hospital, as well as experience elsewhere, it seems that every patient in whom the dura is sutured does badly. There is a tendency to the damming back of the infection in the subdural tissues, leading to meningitis or cortical abscess. Where the dura has been left open, such infected material evacuates itself beneath the scalp, and if the scalp is drained into the dressing no progressive infection arises and the wound heals with little reaction. As a general policy it would seem advisable in cases of this type to leave the dura open and, in addition, to drain the scalp with a small rubber-tissue wick. A case of this type is as follows:

Case 15.—S. D. Pvt., No. 552003, 38th Inf., Co. K. Wounded: October 9, 10 a. m. machine-gun bullet, which made two holes in his helmet. Unconscious five minutes after injury. Wound 10 by 2 cm. over the right parietal eminence, the large diameter being

anteposterior. X-ray examination showed metallic dust in the wound. Shadow suggesting fracture of the inner table. Admitted, Mobile Hospital No. 6, October 9, 6.30 p. m. A. T. S. given. Neurological symptoms: Right pupil larger than the left. Right cremasteric reflex present, more sluggish than left. Left knee jerk more active than right. Left Babinski. Pulse 80. Operation: Tripod incision, with wide incision of wound. Scalp wound did not extend down to skull, but upon examining skull a line of fracture extending backward toward the occipital lobe was present, with no depression of the external plate. Upon opening the skull, two pieces of internal plate measuring 1½ cm. in diameter were found pressing deeply against the dura. One of these lay partially through a small tear in the dura. These were removed. The exposed dura pulsated and there seemed to be no undue tension. It was, therefore, not opened further. The scalp was now closed with S. W. G. sutures. Local anesthesia. October 11: Wound dressed. Looks all right. Pupils equal No Babinski. Diminished sensation left hand and left forearm. Perception of pin prick. Loss of muscle sense and astereognosis. October 13: Stitches removed. Wound healed. October 17: Both pupils dilated equally. React to light. No neurological symptoms. Evacuated sitting.

This case was evacuated to Base Hospital No. 56–A. His condition upon arrival was good, and from there he left on November 14. Wound healed; no symptoms; recommended for convalescent camp.

In some cases, classified as Group III, there was no penetration of dura from the original injury, but there were marked neurological signs, and the appearance of the dura at time of operation indicated hemorrhage and contusion in the adjacent cortex. In three such cases the dura was opened and the damaged tissue beneath evacuated by irrigation and by having the patient cough, and the dura subsequently sutured. These cases did very well. It seems that with a relatively clean external wound excised thoroughly with a block removal of the bone, carried out with the necessary technique, a sufficiently clean operation field can be obtained, so that the dura may be safely opened and sutured.

In contradistinction to the type of cases referred to above, where the original injury has punctured the dura, the contused cortex beneath the intact dura is sterile and if the technique is good, after the evacuation of this contused tissue, the dura may logically be sutured over what is a sterile field. Drainage may be advisable down to the dura to take care of the oozing and any possible contamination of the scalp incision. A case of this type is as follows:

Case 16.—L. F., No. 2255444, 347th Reg. Machine Gun Bat., Co. D. Wounded: September 29, 4 p. m. Gunshot wound head and left buttocks. A. T. S. given. X-ray examination: Head negative. Admitted to Mobile Hospital No. 6, October 3, 12 p. m. Wound on vertex of skull lying in direction of Rolandic fissure, 8 by 1 cm. on left side. The inner angle of the wound extended 20 mm. to the left of median line. Neurological examination: Unable to move ankles and toes, right and left. Right cremasteric sluggish; left active. Right leg rather spastic; deep reflexes right leg hyperactive. Sustained right ankle-clonus. Right Babinski. Operation: Isle-of-Man incision; block removal of bone. Dura injured but not penetrated. There was evidence of underlying contusion of the bone. Dura opened just to the right of the longitudinal sinus, and upon having patient cough a quantity of softened contused brain substance and a clot size of the thumb was expressed. This seemed to be in the leg area. Dura closed. Scalp wound sutured. October 11: Convalescence uneventful. Neurological examination shows equal pupils, the left eye perhaps a shade smaller. Both react to light and accommodation but right more slowly. Visual field normal; retina normal. October 24: Patient can move toes and feet of both legs. Motions limited in power in toe and ankle-joint. Knee motions of both legs normal. Right ankle-clonus; none on left. Babinski is present on neither side. Evacuated.

This case is of particular interest from the neurological standpoint, because the clinical pictures correspond to the longitudinal sinus syndrome described by Sargent and Holmes. The damage to the cortex was so apparent that the dura was incised and the blood clots evacuated. The subsequent history showed a very distinct improvement in the neurological signs.

Group IV.—The treatment carried out at this hospital in cases of this group in which there was extensive damage of the cortex with indriven bone fragments, was less successful than that in any other group. There were several factors which accounted for this. The great majority—one might say practically all of these cases—were the result of tangential wounds in which the damage to the brain was not only direct from laceration by the indriven bone, but also in many cases from the concussion and general commotion of the adjacent area of the cerebrum. If one could have a blow of the same intensity delivered without any fracture of the skull, there would undoubtedly be severe concussion and in some instances a fatal issue from the intensity of the intracranial damage by "commotion"; secondly, it is in these cases that the pathway of infection from the scalp to the intracranial contents is most widely open. Almost without exception, they arrived with gutter wounds, funnel-shaped; and with cranial contents extruding and overflowing the scalp. In such a case—as was the rule at this hospital—if from 24 to 48 hours was taken from the time of the wound to reach the operating table, there is almost sure to be infection in the scalp, in the extruding cranial contents and within the cerebrum itself, about the indriven fragments of bone. It is, then, nearly as important that this particular type of cranial injury should reach the surgeon's hands in a few hours. Unfortunately, the general idea that all head cases travel well before operation has led to the opinion that there is no urgency in forwarding these cases to their operative destination.

If one were fortunate enough to be so situated as to receive these cases in three or four hours after injury, then any who would die after operation would in any event have died of the severity of the intracranial damage. If one waited 10 hours, the majority perhaps of these could be ruled out. Their condition would be very apparently moribund, or they would have begun to improve sufficiently to justify operation. On the other hand, if one waited longer than 15 hours, the danger of propagation of infection in the intracranial structures increases rapidly. It would seem, then, that the optimum time for operation, reasoning purely from the clinical side, would be between 10 and 15 hours after the injury.

It is in this group that the most detailed and careful technique is necessary. It would hardly seem necessary to emphasize the fact that the cerebral tissue must be treated with care, but from observation of the work done at this hospital by teams which had had some neurological training only two operators were among these teams who had a proper respect for the tissues upon which they were working. It is impossible—contrary to the general opinion—to train the average surgeon, however good he may be in general work, in the space of one or two weeks to the necessary fastidious reflexes which are so essential to the successful treatment of these cases. Of six patients evacuated in good

condition three had been operated upon by one team, the operator of which was most conservative in his method of handling the brain tissue.

It would seem that greater emphasis should be laid upon the steps necessary in cleaning up this type of wound. After the preliminary débridement of the superficial structures, repeated coughing and straining of the patient will, as suggested by Cushing, evacuate the contused tract of fragments of bone and sometimes a foreign body, without any further manipulation. It is only after this procedure has been carried to the point where no further results are obtained that one should introduce the catheter. Often it will be found if this is done that the catheter's most important use is as a probe for the discovery of fragments of bone still remaining in the tract. Again, it can not be too strongly emphasized that the catheter in the hands of many without a wholesome fear of the brain tissue may lead to irreparable damage. Indeed in some hands it is as dangerous as the finger and may be thrust very readily into the ventricle, converting the chances of recovery from 60 to 70 per cent to about 20 per cent.

One feels very definitely, after an experience with cases of the type and age received at this hospital, in which infection of the scalp or its intracranial contents is very problematical, that such wounds should be left open for free drainage. It might almost be stated as an axiom that a herniating wound is an infected wound and no amount of mechanical operative manipulation will control such a herniation. The only possible control is drainage, which from the time of operative procedure will in many cases prevent the extension of infection and sometimes even the formation of a hernia. Without drainage there would be an initial herniation and blocking off of the septic material, encephalitis, and the progressive picture which is all too familiar to the cranial surgeon.

The dogmatic statement arising early in the war of 1914–1918, that a cranial wound must be sutured, arose at least in part from the fact that drainage with glass or rubber tubes and dressing of exposed cranial contents with gauze or other adherent material led to fungus formation. A quite different treatment, in which the extruding cranial contents are carefully protected from compression by a "dough-nut" and from adhesion and the tearing of the blood vessels by protective tissues led to the impression that a great number of herniæ will subside in the course of two weeks, and that a still greater number, if this type of dressing is used as a preventive measure, will never occur at all.

The following case is typical of those which recovered in Group IV:

Case 17.—F. S., Pvt., 127th Inf., Co. F. G. S. W. head. Admitted to Mobile Hospital No. 6, October 5. History: Wounded October 4, 9 a. m., by shrapnel. Remembers getting hit; was unconscious for a few minutes. Has suffered since from very severe headaches. Has not vomited. Noticed he saw things double, that he could not see to the left, has been drowsy, has been unable to walk alone. Admitted about 10 p. m. Punctured over tip of left occipital lobe. X-ray examination negative for foreign body. Neurological examination: Headache severe, especially occipital; complete right homonymous hemianopsia. Reflexes all increased; questionable Babinski on the right side. Operation: October 5: 4 a. m.: Tripod incision. Block removal of the fractured area; dura penetrated. Blood clots oozing from cortex, fragments of bone also. One fragment removed 6 cm. from dorsal surface. Careful toilet. Closure with drain. At end of operation, headache had

ceased; temperature 78, pulse 80; diplopia also present. October 11: Wound dressed. Clean; no leak; temperature normal. Right hemianopsia possibly less complete. October 16: Fundi normal. October 18: Dressed. Stitches out. Small area of necrosis in center of wound. No discharge. Hemianopsia as before. October 20: Dressed. Slight granulation of wound. Condition good. October 21: Granulating area practically closed and dry. Wound clean. Right hemianopsia now incomplete and improved. Reflexes normal Evacuated.

Group V.—It is a surprising fact that in this group of cases, where the foreign body was retained within the cranium, the results were distinctly better than in the preceding group. A missile striking the skull at an angle, especially after penetrating the helmet, is frequently deflected and does not penetrate, but by its impact drives bone fragments into the cranium over a large area with great laceration. If, on the other hand, it strikes at an approximate right angle and penetrates, especially if it is of small size, the greater part of the damage is produced by the missile itself, the number of bone fragments is small, and consequently the sum total of the damage done is less than in the tangential blow. Then, too, the penetrating wound frequently produces a punctate wound of entrance with infection; this infection, however, from the scalp surface is not as rapid as through the gutter-shaped wound of the Group IV class.

As regards treatment the same procedures apply as noted under the preceding group. A word should be added, however, in respect to the extraction of foreign bodies. The first reaction on the part of an inexperienced operator is that every foreign body should be removed or an attempt made at its removal. This was the experience in this hospital. One should have definitely in mind the course of the missile, the anatomical structures it has crossed and their function, and above all the relation of the tract and the missile to the ventricle. It is obvious that a tract crossing the neighborhood of the basal ganglia and the internal capsules can be probed or explored with safety in few if any cases. The slight increase in damage produced by the exploratory instrument, no matter how careful one is, may lead to hemorrhage or edema, or introduce infection in areas where encephalitis will be at once fatal.

On the other hand, where the tract passes through cortical or immediately subcortical areas or through the so-called "silent areas," more extensive exploration can be attempted. The danger of opening the ventricle is perhaps the greater one and can not be too strongly emphasized. It should be constantly reiterated that the opening of the ventricle changes the mortality from 30 to 40 per cent to 70 to 80 per cent at least. The employment of special localization methods, such as a Hirtz compass, in the experience gained at this hospital is only a temptation to excess of exploration, and the same to a lesser degree may be true of the use of the magnet. Such procedures in the hands of experienced and conservative operators in some cases would be invaluable, but in the hands of the average operator would be more dangerous than useful. Illustrative cases of this group are the following:

Case 18.—J. M. L. Pvt. No. 372132, 130th Machine Gun Bat., Co. B. Entered Mobile Hospital No. 6 October 1, 1918, at 12.01 a. m. Diagnosis: Multiple G. S. W. History: Wounded September 30, shrapnel wound of head; left arm. Wounded between 6

and 7 a. m. Not unconscious, missile passing beneath helmet; walked to the first aid post alone; not much headache; no diplopia or pressure symptoms. Wound: Point of entrance right occipitoparietal region. X-ray examination: Foreign body 1¼ by 1 cm., lying 2½ cm. beneath mark on hair back of left ear. No fluroscopic evidence of fracture. Neurological symptoms: None. Operation: October 1, 2 p. m. Block removal of fractured skull area. Foreign body removed from right occipital lobe. Wound cleaned. Foreign body was just below the dura; not much cortical laceration; dura left open. Scalp closed tightly. Temperature normal. Left forearm had through and through shrapnel wound; fracture of both bones and loss of bone substance. Débridement: Thomas extension splint. October 4: Wound healing per primum. October 6: Wound healing cleanly. Temperature 98.6. October 8: Wound healed; temperature normal; no headache; reflexes normal; no Babinski; no hemianopsia. Stitches partially removed. October 11: Remaining sutures removed. No headache. Reflexes normal; arm doing nicely with daily saline irrigations. October 14: Head dressed; wound clean and healed; now 14 days old; dressing applied. No diplopia or hemianopsia. Knee jerks active and equal. No Babinski; no motor or sensory disturbances. Left arm wound clean and granulating. Has had daily saline irrigations. Some movement with thumb and first finger. Evacuated lying.

Case 19.—R. L. Sgt. No. 558198, 48th Inf., Co. H. Admitted to Mobile Hospital No. 6, October 18, 8.30 p. m., from Neurological Hospital No. 1. History and notes of neurological hospital: Entered hospital October 1; wounded September 27. Age 26 years. Family history negative. Past history: Graduate, clerical; works at 18 dollars a week. Not interested in sports. Enlisted October, 1917. Arrived France May 23, 1918. In at end of Chateau Thierry operation. Had a severe emotional shock then; saw one of his men hit, went to his assistance, found his head blown off. Nauseated for two days. Carried on in Verdun Sector for two days. At the end of second day, September 27, shell exploded near and he was hit by some of the pieces; received three slight wounds in left arm; one piece of the shell pierced helmet and gave him a slight wound over the parietal region. Blow from this was quite forceful and staggered him, but did not lose consciousness. Believes he bled from the right ear. Was brought back. When first seen wore an anxious expression and was apparently quite confused. October 2: Seen in convulsion, tonic. Mouth was half open; no frothing at the mouth. Physical examination: Deep reflexes exaggerated and exhaustible. Left ankle-clonus, otherwise signs negative. October 17: Later the man gave a clearer account and verified facts above mentioned. In addition, he says there seemed to be about two days he can not account for. Remembers coming to this hospital and that when he was being brought into the hospital he had a convulsion. He noticed that his left arm and leg were beginning to twitch and his throat tightening and remembers no more. He has had same sensation twice since. The past three or four days he has had severe headache, but is better to-day. Pulse 48 to 60, remittent. All neurological signs negative except that superficial, epigastric, and cremasteric reflexes are slightly more active. Eye grounds: Disc margins are both indistinct and decidedly hazy; vessels seem normal. Diagnosis: (1) Psychoneurosis; hysterical. (2) Observation for epilepsy; traumatic. First diagnosis was made on first seeing the patient, but was later changed. Summary: Right head injury, September 27. Two or more convulsions since. Now severe headache. Slow pulse and hazy eye grounds. Entered Mobile Hospital No. 6, October 18. Wound: There is a small healed scar in the right parietal region 1 cm. long over the parietal eminence. Neurological examination: Right pupil measures 5 mm. in diameter, left 3 mm. in diameter. Right optic disc 1½ mm.; swelling of left lid. There is a small retinal hemorrhage in the right eye. Left facial nerve slightly affected during expression. Left arm and hand movements somewhat ataxic. There is also partial loss of muscle sense in the left hand. X-ray examination: Fracture of skull, anteriorally; right antrum cloudy. Foreign body 2 by 3 mm. under mark right side of head (this was about 3 cm. anterior to the wound). Operation: October 18: Straight line incision as for decompression. Small bone defect measuring 1 cm. in diameter excised en bloc. Small opening 1 cm. in diameter in the dura through which brain under pressure was protruding. On coughing, patient squeezed out a blood clot size of a large bean. Subcortical collection of old bloody fluid about 15 cc. in amount. This was removed from the region of the track and also small amount of contused brain was

removed by suction. Foreign body was not removed, although an attempt was made with the magnet. Dura left open; scalp closed. October 19: Headache very much better. Neurological signs as previously noted. October 25: Edema of optic disks subsiding; headache practically disappeared. Neurological signs clearing up. This case was later evacuated in good condition.

Group VI.—An example of a favorable case of this group is the following:

Case 20.—F. M., Cpl., No. 1897372, Machine Gun Co., 325th Inf. Entered Mobile Hospital No. 6, October 12. Wounded October 11, 4 p. m. by shrapnel; unconscious 12 to 15 minutes; nausea and vomiting; weakness left leg immediately. Blurred vision; bright flashes of light. Persistent headache. Wound: Lacerated wound 2 cm. in diameter over left parietooccipital region. X-ray examination: Foreign body $\frac{5}{10}$ by $\frac{3}{10}$ cm., 1 cm. under skin mark just above ear. Neurological examination: Right hand and arm spastic and weak. Loss of sensation of right upper extremity as well as lower; no Babinski. Patella clonus on the right. Knee jerks hyperactive, but equal. Left homonymous hemianopsia. Operation: Small laceration of the scalp. Two by three cm., excised. Bone removed en bloc. Dura punctured and three indriven fragments removed. Foreign body found in scalp. Large masses of blood oozed from cortex, cerebral fluid leaking in small amounts. Irrigation of wound produced severe headaches. It was thought that the fluid entered the ventricle. Scalp closed tightly; dura left open. October 14: Wound clean; temperature normal; no subjective changes. October 16: Fundi normal; wound clean; several sutures removed. October 18: Remaining sutures removed; temperature 98.4. Has had occasional headache, and temperature reached 100 last night. Profuse discharge from scalp wound. October 22: Complains of slight headache; no ocular symptoms or nausea; hemiplegia improving. Sense of position and common sensation absent. Heat and cold preserved. No fever for past three days. Wound draining slightly; condition good. October 24: Redressed. Condition improved. October 25: Dressed. Drainage has stopped. Wound healed. Neurological condition improving. On evacuation, condition good.

Group VII.—A case which recovered in this group is as follows:

Case 21.—W. D. P., Pvt., No. 573950, 12th Machine Gun Battalion, Co. C. Admitted to Mobile Hospital No. 6, October 2, 1918, at 4.15 p. m. History: Wounded October 2, at 10 a. m., machine-gun bullet, penetrating right upper eyelid. Complete collapse of right eye, bullet apparently having passed posteriorly. X-ray examination: Machine-gun bullet lying in the cranial cavity, 1 inch to the right of median line over roof of the orbit and back of the posterior border of the orbital cavity, directly at the intersection of lines from two skin marks. Neurological examination: No signs. Operation: Enucleation of right eye; removal of contused brain tissue; bone fragments and bullet from a bone defect in supraorbital plate very deep down in frontal lobe. Plastic closures of structures about the right orbit. October 17: Convalescence uneventful; no neurological signs; evacuated.

Group VIII.—Two cases of traversing wounds in this group recovered, and will be given in detail.

Case 21.—L. S., Pvt., No. 2661431, 59th Inf., Co. B. Admitted to Mobile Hospital No. 6, September 30. History: Wounded September 29. Point of entrance left frontal; point of exit right frontal about 2 inches above the external orbital process. Lacerated wound at higher point about 2 cm. in diameter, both outside of the hair line. Not unconscious; walked in, complaining only of some frontal headache. Neurological examination negative. Operation: Wounds excised and connected, with thorough débridement. Dura penetrated and brain oozing out. Edges cleaned, and toilette of entire wound; drainage at either end and with suture of scalp between. October 11: Neurological note says headaches the whole time and eyes burn; otherwise feels well. He states at this time that he remembers everything from the time he was hit; did not vomit; walked to dressing station; had no pain, but was dazed and his head began to ache soon after. Is perfectly rational at present; relevant and coherent; euphoria; no irritability. October 14: Sutures removed; wound healing. October 17: Convalescence has been uneventful. Evacuated.

CASE 22.—J. G., Pvt., No. 1448900, 37th Inf. Admitted Mobile Hospital No. 6, September 30. History: Wounded by machine-gun bullet September 28. Condition stuporous: answers questions slowly; retarded; no aphasia. Wound: Point of entrance left occipitoparietal; point of exit right occipitoparietal, both 2 inches above left occipital protuberance and 3 inches to the right. No foreign body. Neurological examination: No evidence of cranial nerve injury; complains of loss of vision in the right eye; distinguishes light, right eye; recognizes objects with left eye. Operation: Débridement scalp and bone both exit and entrance. Suture. October 4: Pupillary examination, normal. Fundus: Slight but definite hyperemia; no swelling; vision both eyes nil. October 6: Slight convulsion, seizure lasting five minutes. Says he can hear well. October 9: Thinks he can distinguish light. Wound clean. October 13: Vision improving; distinguishes objects both right and left eye. October 17: Wound healed. Vision and memory returned. Cerebration keener. Evacuated.

SINUS (VENOUS)

The following case is illustrative of a wound which involved the longitudinal sinus:

CASE 23.—Pvt., No. 220739, 362d Inf., Co. G. Entered Mobile Hospital No. 6, September 29. History: Wounded, September 28. Shrapnel passing through helmet; not unconscious; did not vomit. Slight headache. Condition: Walked into the hospital; headache only at present. Wound: Slight lacerated wound over sagittal suture at the occipitoparietal junction. X-ray examination negative. Neurological examination negative. Operation: Excision of scalp wound, small indentation of external table measuring 2 cm. in diameter; square piece of bone removed en bloc over area 5 cm. in diameter. Depressed fracture inner table; small fragments piercing longitudinal sinus with a linear tear about 1 cm. in length; no clot. Bleeding controlled by cotton and a slip of muscle placed directly over the tear. Scalp sutured tightly. October 2· Wound healing primum; no neurological signs. No headache. Patient evacuated.

SUMMARY

The following table gives the complete data as regards the cranial injuries handled by this hospital:

	Evacuated	Died	Total	Mortality, per cent
Cranial: Group I	69	0	69	0
II	32	1	33	3
III	14	2	16	12
IV	6	17	23	74
V	11	3	14	21
VI	1	5	6	83
VII	1	2	3	56
VIII	2	2	4	50
IX	0	2	2	100
Sinus	4	1	5	20
	140	35	175	20
Craniotomies	71	35	106	33
Dural penetration	37	31	68	45

The advantage of such a specialized unit as this may be summarized as follows: 1. Refinement of technique, approximating that really necessary to do even fairly satisfactory work, is possible. 2. Changes in technique, and the adoption of adjuncts, such as X ray are rapidly possible in a group with a centralized control, such as this. 3. The training of surgical teams, and the insistence upon the most fastidious technique can be accomplished readily only in such a hospital. 4. It is possible to get "team play" between the

ophthalmologists, maxillofacial surgeons, X-ray department, pathologists, etc., in one hospital; it is exceedingly difficult to do so in all of a dozen or more hospitals.

The disadvantages, as they appear in this experience, were principally those of transportation and triage. This hospital was situated at such a distance from the front that during a major portion of the fighting, cases reached it upon an average of 36 hours after injury. In addition, there were too many steps in transportation; that is, all cases would be evacuated through one and sometimes through two hospitals, at which points there would be a delay of sometimes 12 or even 24 hours. These cases did not suffer from length of transportation to any great degree, but they did suffer, as shown by data, especially those under Group IV, by the prolonging of the preoperative period, during which infection was uncontrolled. It should always be stated as a corollary to the axiom, "Head cases bear transportation well before operation," that a delay of 24 hours increases the chances of infection and decreases the chances of survival almost as markedly as it does in penetrating wounds of the abdomen. This is shown by the high mortality in Group IV, where the wounds were open, cranial contents extruding, and infection had a wide pathway of entrance, whereas in the other groups in which the point of penetration was smaller, and the path of infection more devious, the mortality was as low, and even lower, than the ideal figure given in "Instructions to the Neurological Surgical Teams."

CHAPTER III

MANAGEMENT OF GUNSHOT WOUNDS OF THE HEAD AND SPINE IN FORWARD HOSPITALS, A. E. F.

CRANIOCEREBRAL SURGERY PRIOR TO OUR ENTRANCE INTO THE WORLD WAR

Wounds of the head in the war, 1914–1918, were, generally speaking, of a more serious nature, as was true of all wounds, than was the case in former wars, due principally to the short-range firing of trench warfare, to the employment of intense artillery fire, much of which was high explosive, and to bombing from the air. Thus the relatively great number of head wounds requiring surgical intervention presented a problem seriously demanding a solution. It was evident from the first that the victims of cerebral injury were likely to constitute the last residium of the wounded needing hospitalization long after the end of hostilities.

There was a lack of unanimity of opinion, with respect to the management of these cases, which persisted throughout the war. This was more marked, however, during the first two years. Toward the latter part of this period (1916) it was considered good practice to transfer head wounds to the rear, in view of the fact that patients with head injuries bore transportation badly following operation. This, of course, meant a delay of 36 to 72 hours and longer. When to operate, which cases to operate, the anesthetic to be used, etc., gave rise to much discussion.

De Martel [1] and Pauchet [2] were among the first to advocate local anesthesia in operations on the head. This presented several advantages: It did not raise the blood-pressure, either by its action per se, or as the result of the patient's struggling during the induction stage of anesthesia; and it enabled the patient to assist at the operation by coughing, which oftentimes extruded pulped brain substance, débris, and particles of bone, after trepanation of the skull and exposure of the dura.

The British surgeons advocated osteoplastic bone flaps with the wound at or near the center of the flap (see figs. 1 to 4). The finger was used in palpating for foreign bodies, but gentleness in the use of the finger was emphasized. This in itself, in experienced hands, was not a serious drawback to the operation, but as many men, with limited experience in this branch of surgery, were called upon to care for these cases, lack of gentleness was very often the cause of much additional damage to cerebral tissue, and there was a high mortality. The French employed trepanation of the skull, and some surgeons habitually removed shell fragments and bullets under the fluoroscope. This method had several distinct disadvantages: It was not only necessary to remove the metallic foreign body, but pieces of indriven bone, hair, pulped brain, and filth as well; it served as a temptation to the surgeon simply to get the foreign body itself

and to content himself with a more or less incomplete toilet of the tract. Furthermore, seeking the metallic fragment in the brain under the fluoroscope caused needless and, oftentimes, much additional damage to the brain. In

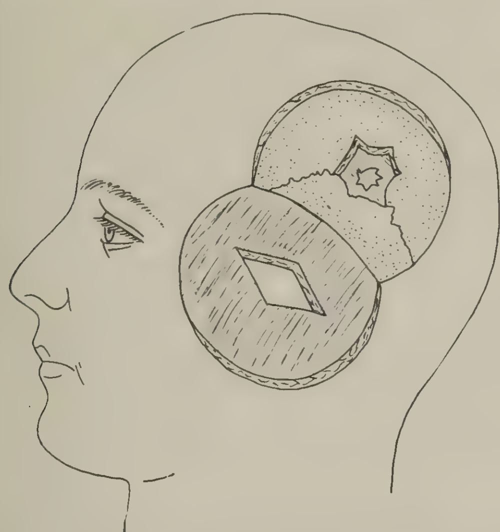

FIG. 1.—This and Figures 2 to 4, inclusive, illustrate the technique of the osteoplastic method with the wound near the center of the flap

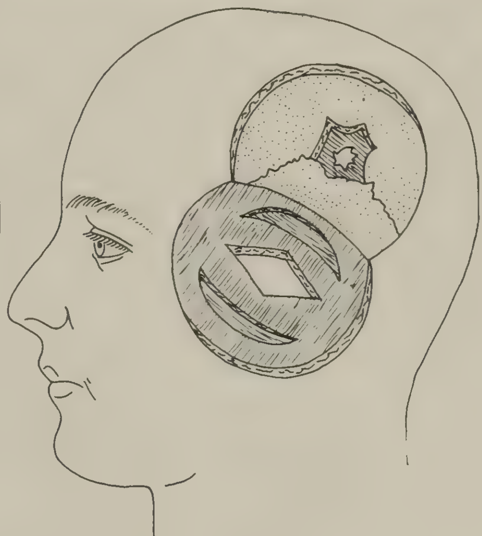

FIG. 2

selected cases, however, after a careful toilet of the tract and when the foreign body could not be located definitely or removed by a powerful magnet, this method was the only solution in removing the shell fragment or bullet. The

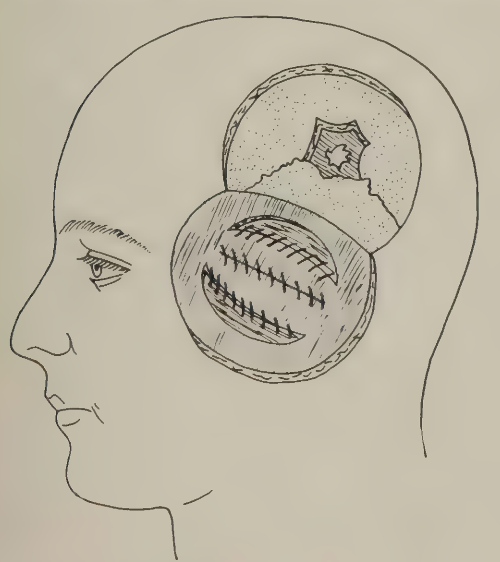

FIG. 3

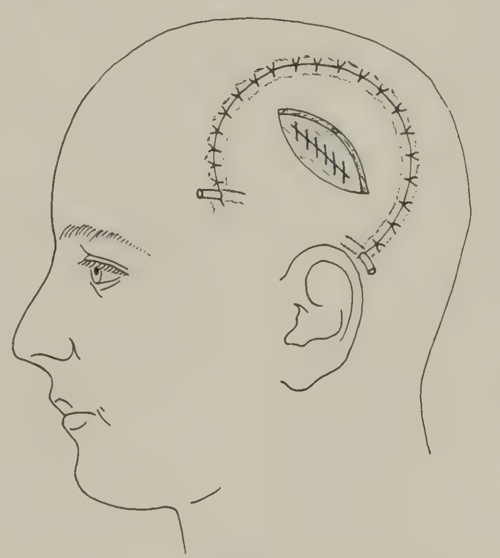

FIG. 4

French insisted also on the importance of removing all foreign bodies at the first operation; if they were at all accessible, and the resulting late brain abscesses in cases of retained missiles have verified the wisdom of this contention.

As stated, it had been the custom in the British Army to route all head cases to the base, and large numbers of them had passed through the hands of Colonels Sargent and Holmes at General Hospital No. 13, at Boulogne, where it was customary in the case of penetrating wounds to turn down an osteoplastic flap, including the wounded area, to remove the foreign bodies, and to replace the flap, draining from either or both lower angles. The wound itself was often closed from the inside. With this method the mortality was high and secondary infection was relatively common.

During the Paschendale battles in the summer and autumn of 1917 a new program was put into operation whereby the head injuries were routed to one of the casualty clearing stations at Proven and operated upon before being sent

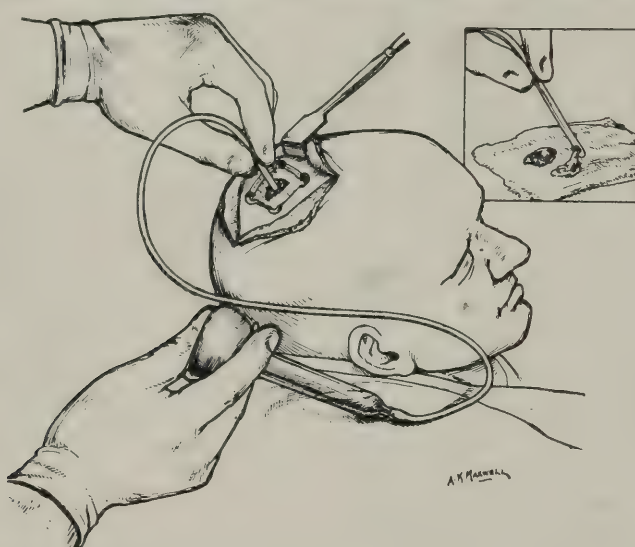

FIG. 5.—Sketch illustrating the method of suction of the tract of a penetrating wound while searching for foreign bodies

to the base. To this station Cushing [3] and some of his assistants from United States Army Base Hospital No. 5, serving with the British Army were attached and a new method of procedure was adopted. In simple terms, it consisted in approaching the tract in the brain through the wound. This was done by excising the scalp wound down to the skull and employing the tripod or the Isle of Man incisions further to expose the skull. A piece of bone around the hole in the skull was then removed en bloc. A soft rubber catheter was passed into the tract in the brain to locate foreign bodies, a syringe being used to produce suction. At the completion of the operation the scalp was tightly closed by two layers of fine interrupted silk sutures. This method lowered the mortality, prevented secondary infection, and lessened the possibility of hernia cerebri. This modification of the technique formerly employed had several very important advantages: It did not produce any more damage to cerebral tissue and it tended to prevent secondary infection from the outside. The wound, if it tended to break down, always opened at the junction of the three triangular flaps.

This technique lowered the mortality from between 50 and 60 per cent to 28.5 per cent in one of the early series. It was generally accepted and practiced in the American and the other Allied Armies.

CLASSIFICATION OF HEAD INJURIES

The classification of head injuries which follows is that adapted by Cushing in his critical study of the cases which had passed through his hands at a British casualty clearing station during three months in 1917.[4]

Grade I.—This group comprised wounds of the scalp, with both cranium and dura intact, though occasionally complicated by an underlying cerebral contusion. Of 22 cases observed, one was fatal, a mortality of 4.5 per cent.

Grade II.—Wounds producing local fractures of variable types, with the dura intact, were placed in the second grade. They were subgraded further into Type A, when there was depression of the external table (fig. 6). In the 54 wounds graded thus, local contusions of the brain, or extra dural extravasation were fairly common. Among the 54 cases of this grade observed 5 deaths occurred, or a mortality of 9.2 per cent.

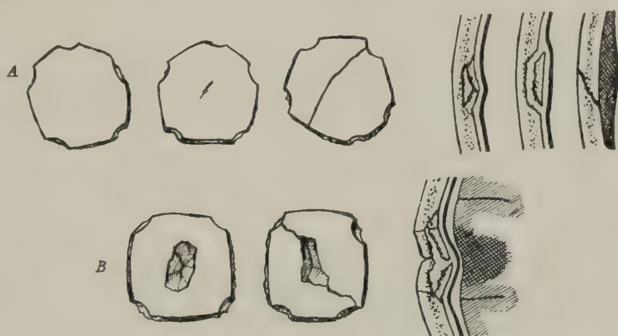

FIG. 6.—Grade II; Wounds producing local fractures of variable types, with the dura intact. Type A, without depression of external table; type B with depression of external table

Grade III.—Local depressed fractures of various types, with the dura punctured, were placed in this grade (fig. 7). Among the 18 cases observed, because of the inevitable local contusions, positive neurological signs usually were present. Two deaths occurred, giving a mortality of 11.8 per cent.

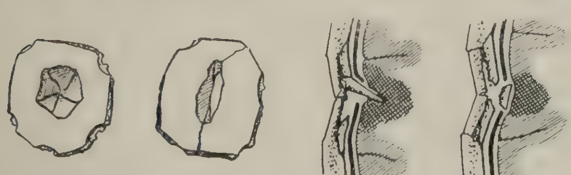
FIG. 7.—Grade III: Local depressed fractures of various types, with the dura punctured

Grade IV.—In this grade wounds, usually of the gutter type, with detached bone fragments driven into the brain, were placed (fig. 8). Twenty-five cases were observed. Local contusion was severe, and extrusion of the brain almost inevitable. Fungus cerebri and encephalitis were common sequels. Six deaths occurred among the cases of this grade, giving a mortality of 24 per cent.


FIG. 8.—Grade IV: Wounds, usually of gutter type, with detached bone fragments driven into brain

Grade V.—This grade comprised wounds of the penetrating type, with lodgement both of projectile and bone fragments (fig. 9). The brain frequently was found extruding, and there was much contusion along the tract. In such wounds, symptoms depended on the size and course of the missile. Common sequels noted were early compression and late abscess. Among the 41 cases of this grade 15 deaths occurred, 36.6 per cent.

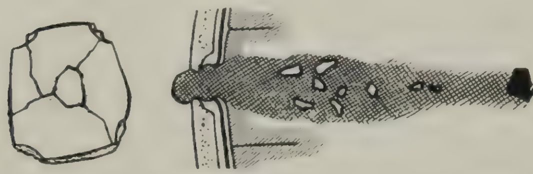

FIG. 9.—Grade V: Wounds of penetrating type, with lodgment both of projectile and bone fragments

Grade VI.—Wounds of this grade comprised those in which the ventricles were penetrated (Type A) by bone fragments or (Type B) by missiles (fig. 10). Cerebral lesions in this grade were the same as in the wounds of the two immediately preceding grades. The escape of cerebrospinal fluid is constant; hemorrhage into, or subsequent infection of, the ventricles is common. In 14 cases in which the ventricles were penetrated or traversed by bone fragments, 6 deaths occurred (42.8 per cent); in 16 cases in which the projectile penetrated or traversed the ventricles, the mortality was 100 per cent.

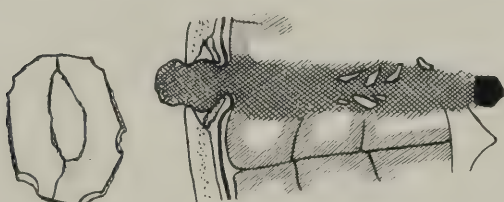

FIG. 10.—Grade VI: Wounds with ventricles penetrated or traversed (*a*) by bone fragments, (*b*) by projectile

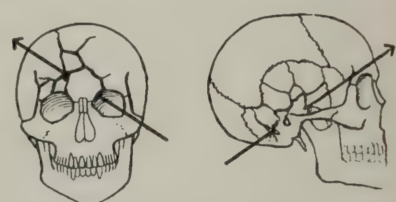

FIG. 11.—Grade VII: Wounds of craniocerebral type involving (*a*) orbitonasal, (*b*) auripetrosal region

Grade VII.—Wounds of this grade were of the craniocerebral type involving (A) the orbitonasal, or (B) the auripetrosal region (fig. 11). In these wounds the brain is commonly exposed and extruding; the fractures are radiating; nasal or petrosal cavities are opened; meningitis is common. Among 15 cases observed 11 deaths occurred (73.3 per cent).

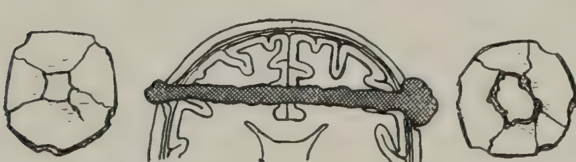

FIG. 12.—Grade VIII: Wounds with craniocerebral perforation

Grade VIII.—Craniocerebral perforations were placed in this grade (fig. 12). Extensive cranial and cerebral damage is common to such wounds; death usually is due to intracranial hemorrhage and compression. Among 5 of these cases observed, 4 deaths took place (80 per cent).

Grade IX.—Craniocerebral injuries, with massive fracture of the skull were placed in this grade (fig. 13). Such injuries involve widespread cerebral contusion; compression phenomena are common. Of 10 of these injuries one half died.

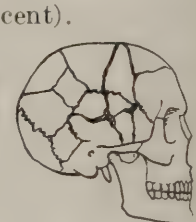

FIG. 13.—Grade IX: Craniocerebral injuries with massive fracture of skull

ROUTINE PRELIMINARY TREATMENT OF HEAD INJURIES AT AN EVACUATION HOSPITAL, A. E. F.

Though having received some instruction in neurosurgical diagnosis before being sent overseas the members of the hastily organized neurosurgical teams attached to the evacuation hospitals of the American Expeditionary Forces had had no experience whatsoever with war wounds in general, much less with the complicated and special procedures which the treatment of craniocerebral injuries demanded. Profiting by such instructions as were given by the senior consultant, neurosurgery, the following routine, more or less modified by individual experience, was so far as possible put into operation.

Patients admitted to the receiving room were divested of all their clothing, which was deposited in a tent set aside for that purpose. They were covered with blankets and carried into the adjoining room where their field cards were inspected. Their heads were completely shaved and a hypodermic injection of 1,500 units of antitetanic serum was given in the abdominal wall, if not previously administered at the triage hospital.

The patients were then sent through the X-ray room where, in each instance, an attempt was made to determine the presence, the location, and the depth of the intracranial foreign body. By means of the fluoroscope crosses, at right angles, were made on the scalp with a lunar caustic pencil. Skiagraphs were then taken, laterally and anteroposteriorly, and delivered to the operating room, and placed in the diagnostic box for the surgeon's reference. When this was completed, patients were placed in a room near by the operating room which could accommodate 30 men, awaiting their turns for operation. Operable cases in shock were carried to a special tent where they were given hot black coffee, and morphine hypodermatically. They were covered with blankets, so arranged as to drape over the sides and ends of the bed. A lighted oil stove was then placed under the bed. An enlisted man constantly watched such stoves. From time to time the patient's condition as to pulse, temperature, and blood pressure was noted. Immediately upon recovery from shock they were operated upon. In instances of severe hemorrhage, citrated blood transfusion was employed, when possible, in addition to the treatment already described. Inoperable shock cases were placed in another special tent where most of them died. Their treatment was the same as that described for operable cases in shock, with the exception of blood transfusion, as the scarcity of blood rendered it impossible.

In the operating room the surgeon in charge employed three tables. A hurried but careful examination was made of each patient before operation, usually on the operating table. The patient was then given morphine, three-eighths grain hypodermatically, if no morphine had been previously given within four hours. At the operating table, patient sitting with a roll under the neck, the scalp was washed with green soap and sterile water and wiped off carefully with ethyl alcohol. Patients that required suboccipital exploration, or decompression, were placed face downward on the regulation stretcher, the forehead resting on one of the slings stretched between the two handles, and the stretcher placed on the operating table. Making a mental picture of the style of incision desired, tripod, Isle-of-Man, or flap, and its possible extent

a block of scalp was injected. A larger needle was then passed down to the pericranium, injecting deeply within the block. Large wounds often required plastic flaps of scalp to cover cranial defects, even though large areas of intact skull were denuded thereby. Thirty cubic centimeters of a 1 per cent novocain solution, to which one-sixty-fourth grain of adrenalin chloride was added, was usually sufficient for one case.

TREATMENT OF DIFFERENT GRADES OF HEAD WOUNDS

WOUNDS OF THE SCALP

All scalp wounds were considered potentially serious, even in the absence of neurological findings, until proved otherwise by operative exploration. The importance from a military standpoint of caring for these cases in the forward area can not be overestimated, as such wounds, if not complicated by fracture and cerebral injury, heal readily, permitting an early return of the soldier to duty. Many slight cases would otherwise be evacuated to the rear. Very slight wounds of the scalp were often found to overlie a penetrating wound of the skull. These cases may prove to be very serious, as the bone may be perforated without apparent fracture.

FIG. 14.—The in-driven fragments of inner table (natural size)

Other cases, with the external table intact or with only small linear fractures apparent from the outside, may have extensive comminution of the internal table, with perforation of the dura and bone fragments in the brain. In the presence of neurological symptoms one should always drill down to the inner table, and if the symptoms are very marked the dura should be investigated. If found tense, even though intact, it should be opened. In cases where the scalp wound is infected and the patient presents marked signs of cerebral injury the excised wound should be sterilized as well as possible and a block of bone removed, exposing the dura. If the dura is found to be perforated, the in-driven bone and pulped brain should be removed by the patient's coughing, by irrigating through a soft-rubber catheter, using sterile decinormal saline solution, suction, and the use of an esquillectomy forceps in removing the bone fragments. When the tract is clean, it is sterilized by injecting a small amount of dichloramine-T, with eucalyptus oil or ethyl alcohol, through the catheter on withdrawal.

A lumbar puncture should be done where symptoms of meningitis are present after injury. If the diagnosis is verified by spinal puncture, the case should not be operated upon, as such cases invariably die, operation or no operation. Figures 14, 15, and 16 reveal the findings in a case reported by Cushing, in which the external table was practically intact. Very extensive wounds of the scalp may occur without the slightest injury to the skull or the brain, but the reverse is much more common, namely, an apparently trifling though penetrating scalp wound which conceals an extensive craniocerebral injury.

Many small depressed fractures of the outer table were produced by shell fragments of spent velocity; they were usually tangential. On drilling down through such a fracture the inner table was often found to be intact. These cases in most instances recovered as rapidly as simple scalp wounds and, in the absence of neurological symptoms, could be returned to their organizations at the front.

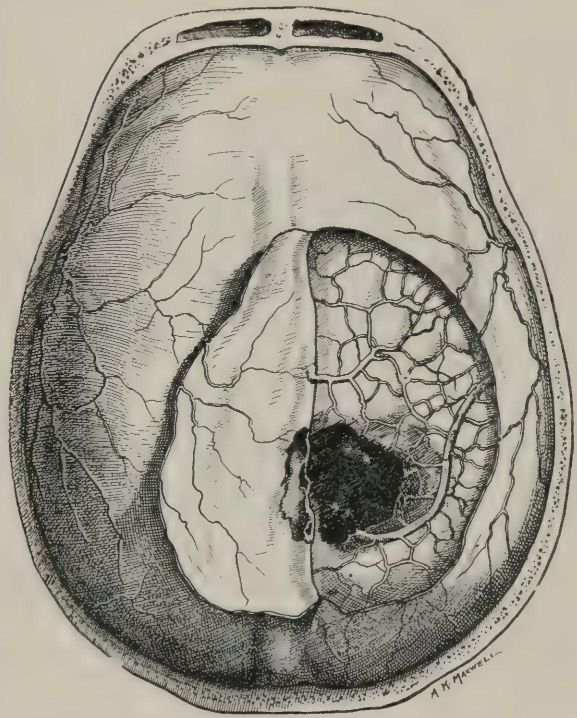

FIG. 15.—From a sketch at autopsy after removing calvarium

When fractures of the inner table were disclosed with an intact dura, the membrane was not opened unless it proved to be tense or discolored when it was incised and the underlying brain inspected. If the brain proved to be pulped, the devitalized brain tissue was removed by irrigating gently with sterile decinormal saline solution, using the soft-rubber catheter, syringe, and bulb. If hemorrhage was present, the blood was evacuated, and any pial vessels found bleeding were ligated with fine silk or preferably caught with silver clips. Naturally, when a torn dura has been disclosed, the question of advisability of incision or otherwise will not arise.

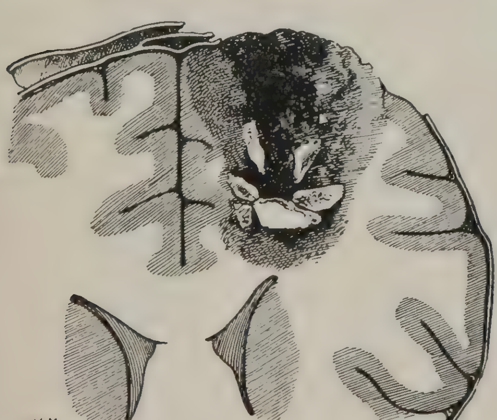

FIG. 16.—Section through the contused area, showing position of bone fragments

Fractures of both tables, with perforation of dura and with bone fragments in the brain, constitute a type of injury which is often complicated by the lodgment of one or more shell fragments or a bullet. The treatment of these cases will be described more fully under "Operations." Figures Nos. 17, 18, 19, and 20 are illustrations of this type of fracture.

It is appropriate here to consider briefly "bursting" fractures of the skull, as they were sometimes associated with local fractures. "Bursting" fractures were the result of perforating wounds, violent explosions, or falls, or of being struck by soft bodies. Some of these fractures were so extensive as to involve practically the entire

FIG. 17.—Trepanation block, showing behavior of thick skull to tangential wound

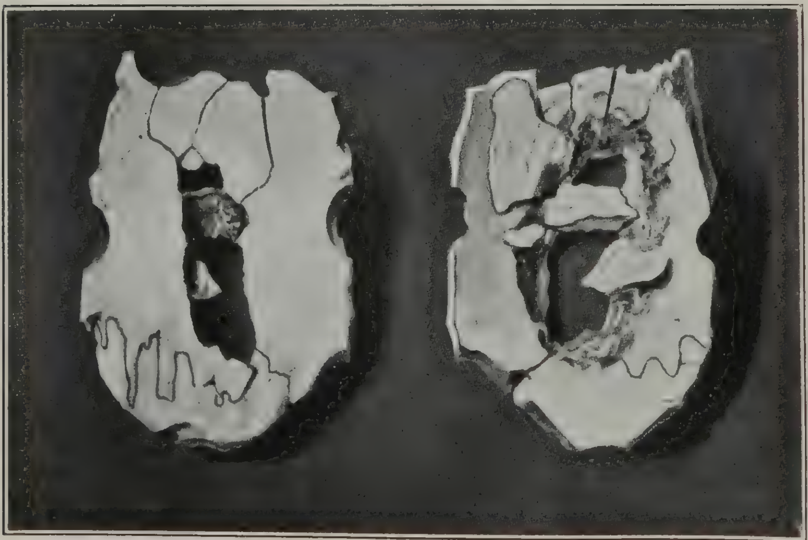

FIG. 18.—Bone block. Specimen on left shows interparietal suture and fissures radiating from gutter; on the right, a few fragments of internal table attached

skull. Numerous linear and radiating fractures occurred at the point of injury, while every fossa might show fractures. Unilateral and bilateral decompressions were performed on some of these cases, but the resulting cerebral edema was so great that recovery was rare.

Cases of this type that appeared to be hopeless but did not develop a fatal edema and were not operated upon were in some instances evacuated alive.

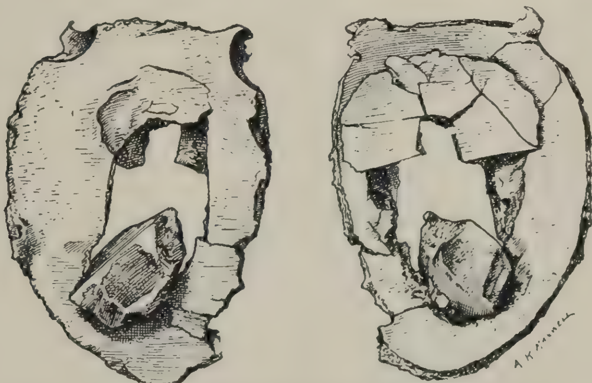

Fig. 19.—Example of lodged shell fragment in an oblique gutter wound

Operation

The prepared head, with the field of operation surrounded by sterile towels held in place by skin clips, being ready for operation, the scalp wound was excised down to the skull, and the excised tissue, forceps, and knife were placed in a basin and removed.

Fig. 20.—Small gutter fracture in thin skull; complete dislodgment of fragments

The scalp incision.—The type most generally used was described by Colonel Cushing as a tripod incision. Three straight incisions were made to the excised area in such a manner as to best facilitate the approximation of all edges. No general rule can be made, as the angles of the formed incisions differed with the location and the general outline of the excised area. Rat-toothed forceps were now placed on the galea, strips of gauze passed through the handles of the forceps attached to each flap, and the flaps undermined. The strips of gauze were then fastened to the sterile sheet, serving as retractors, and the skull inspected. If the skull was intact, the wound was wiped out with

ethyl alcohol. The galea was then united with interrupted sutures of silk, or No. 0 or No. 1 chromic gut, and the scalp closed with silk sutures. The scalp sutures were removed in two to three days. Figure 21 illustrates the tripod incision.

The three-legged or Isle-of-Man incision was the incision used in larger wounds. The technique was the same as that described in the tripod incision, except that each of the three incisions had a knee (fig. 22).

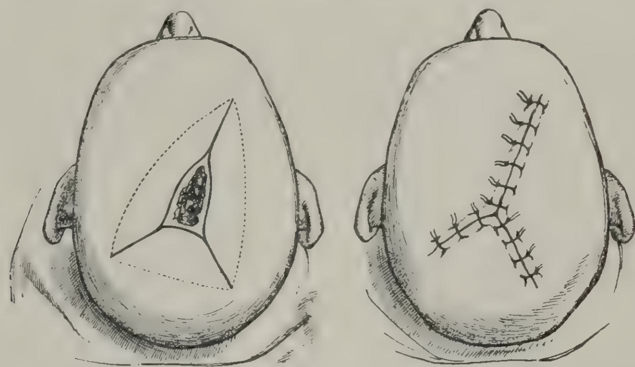

FIG. 21.—Tripod incision for small irregular wound of vault. Dotted lines indicate area of reflection of flaps. (Cushing)

Flap incisions were employed in wounds of the temporal and suboccipital regions, especially in cases that required drainage. Occasionally straight incisions were used in the temporal region. Large osteoplastic flap incisions were employed in searching for a shell fragment or bullet, intracranial, but opposite to the wound of entrance.

The craniotomy.—The instruments required for trepanation of the skull are: A cranial perforator, a half-inch burr, a dural separator, and a pair of Monte-

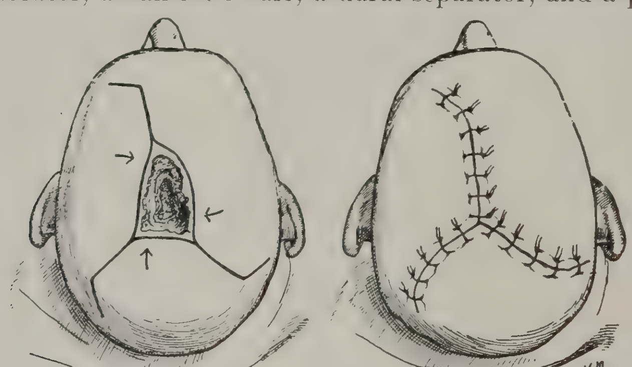

FIG. 22.—Three-legged (Isle of Man) incision for larger wound of cranial vault. (Cushing)

novesi or De Vilbis linear cutting forceps. The cranial perforator was used to perforate the bone down to the inner table or through the inner table at a small point. This was followed by the burr. The dural separator then was used to elevate fragments of the inner table at the bottom of the opening made by the burr, and rotating it between the thumb and forefinger, the dura was separated well beyond the margins of the opening made by the drill. The linear cutting forceps then followed the burr.

Trepanations were triangular, quadrangular, or pentagonal, drilling 3, 4, or 5 holes. Pentagonal trepanation was performed when by so doing the defect might be smaller. Quadrangular and rectangular trepanations were usually employed in larger injuries. Figure 23 illustrates a quadrangular trepanation.

The osteoplastic flaps used were those common to surgery of civil life. The enlargement of an already existing defect in the occipital and lower frontal regions where the bone is thick and as small a defect as possible is desired, was done by the use of rongeurs. If the injury was over a sinus, trepanation was always done.

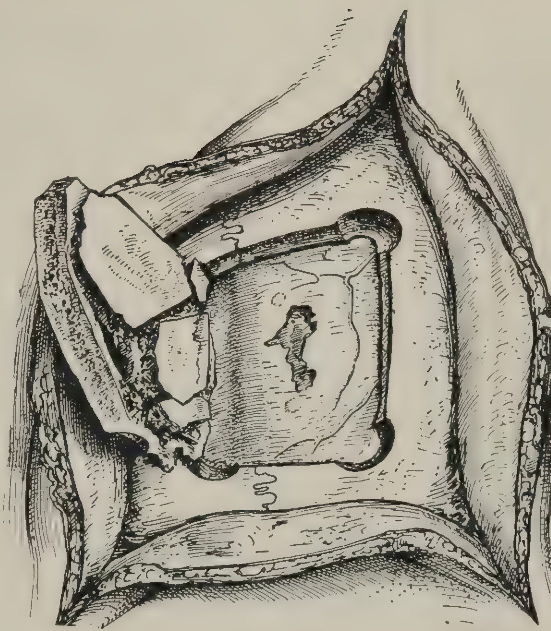

FIG. 23.—Quadrangular trepanation

The intracranial procedure.—The perforation in the dura was not enlarged, unless the opening was very small. Pieces of indriven bone, hair, or felt from the inside of the helmet, if found in the opening, were removed. A soft-rubber catheter was then passed through the opening in the dura and into the track in the brain, and bone fragments located in this manner were removed by the use of an esquillectomy forceps. Pulped brain and small pieces of bone were removed from time to time during the progress of the operation by the patient's coughing, by irrigating gently through the catheter with sterile decinormal saline solution, and by gentle suction, using glass syringe and bulb. As larger pieces were located by the catheter, they were removed. A shell fragment or bullet, when located, was removed by the esquillectomy forceps, and the tract again very gently explored with the catheter, searching for more bone fragments. Figure 24 illustrates the use of the catheter in locating foreign bodies.

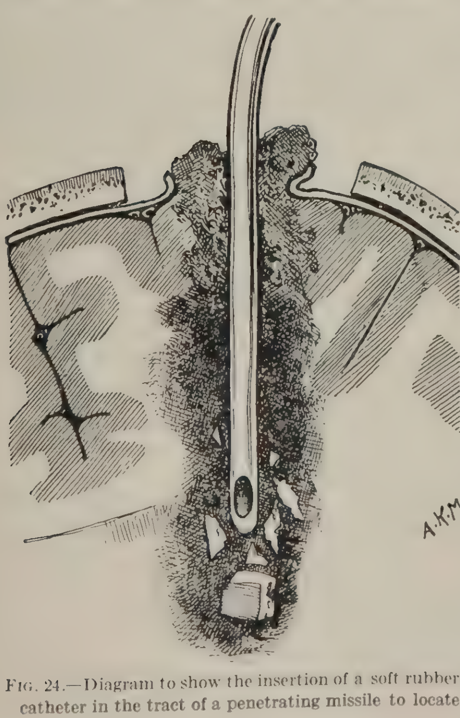

FIG. 24.—Diagram to show the insertion of a soft rubber catheter in the tract of a penetrating missile to locate foreign bodies

Only in cases where more than one tract existed in the brain, with shell fragments at different levels and widely separated one from another, was the finger employed to locate them, and then with the utmost care and gentleness to avoid doing more damage than already existed (figs. 25 and 26). Opinions differed as to whether or not foreign bodies, difficult of access, should be removed. Foreign bodies in the brain should always be removed, if at all possible, as the chances of infection are very much increased, especially if bone fragments and, possibly, hair and filth lie below them.

It was rarely found to be necessary to remove a shell fragment or a bullet under the flouroscope. This should never be done, unless the foreign body can not be removed by the usual method and no magnet is at hand, as more or less additional damage always results.

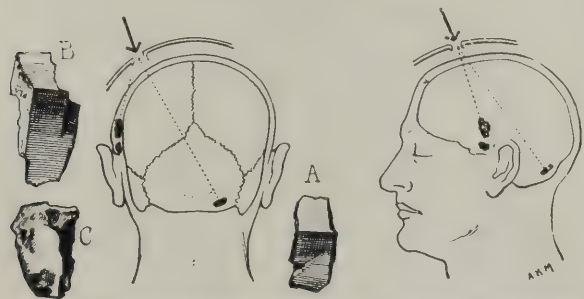

FIG. 25.—Split shell fragments with separate tracts and fragments at varying depths. (Cushing)

In searching for shell fragments where no tract existed from the side of the brain approached in the operation, i. e., in cases where osteoplastic flaps were turned down opposite to the wound of entrance for the removal of a shell fragment or bullet in the opposite hemisphere, a telephone probe was used. A telephone probe is an ordinary silver probe, 8 or 9 inches in length, to which one of the wires of an ordinary telephone receiver is attached. The other wire is attached to an empty brass cartridge shell. Taking care that the metal cartridge shell does not come in contact with any metal fillings, it is placed in the mouth of the patient. The probe is then used to search for the foreign body. When it comes in contact with the steel fragment, a sputtering is heard, as in the presence of overcharged electricity. This proved to be a very useful instrument in searching for shell fragments as already described, in the cerebellum, the posterior fossa, and the lateral ventricle.

Puncture of the lateral ventricle was done where bulging existed after turning down a large osteoplastic flap in the search for larger shell fragments opposite to the wound of entrance. In these cases the original tract was first cleansed as deeply as possible and ethyl alcohol, or dichloramine–T with eucalyptus oil, injected.

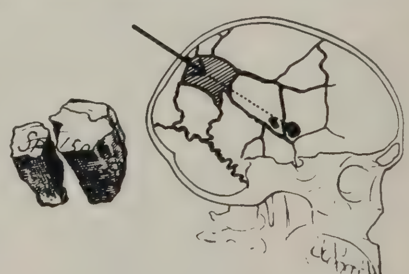
FIG. 26.—Split shell fragments in temporal lobe. (Cushing)

In cases where the shell fragments entered the brain through the orbit, the destroyed eye was enucleated, the indriven pieces of bony orbit removed, and the pulped brain cleansed from the tract in the brain. The deep bone and shell fragments were removed by the esquillectomy forceps as these fragments were located by the catheter. When the tract was clean, it was injected with

dichloramine-T with eucalyptus oil, or ethyl alcohol through the catheter. Occasionally this type of wound was approached through a supraorbital incision, enucleating the eye at the completion of the operation.

Cases with a large shell fragment that had passed through the brain from above and embedded itself in the roof of the mouth were treated from above as already described for penetrating wounds of the brain. The embedded shell fragment was then removed through the mouth, using large foreign body forceps.

Bullets or larger shell fragments that passed through the anterior portion of the frontal lobe and lay on the basilar process of the occipital bone in front of the spine were removed through the original tract.

Shell fragments that penetrated the middle fossa from below were removed by first rendering approach possible. The zygoma was resected and the opening in the skull débrided by using small rongeur forceps. The catheter was then inserted and pieces of bone and the shell fragment were removed when located.

Perforating wounds of the skull were sometimes associated with bursting fractures. The treatment consisted of trepanation of the wounds of entrance and exit, cleansing the tract from both ends of all pulped cerebral tissue and pieces of indriven bone, some of which were found nearer to the wound of exit than to that of entrance. Perforating wounds of the temporal region often were associated with blindness due to a severing of either the optic nerves or the chiasm.

BRAIN ABSCESS

Operations on brain abscesses due to war wounds gave a high mortality. Meningitis resulted because the abscess, when opened, was usually opened through the uncontaminated subdural space. When abscesses were opened at a point in the skull directly over the site of the injury, through a relatively small opening, without disturbing the adhesions to the inner table and opening the dura carefully, it was possible, in some cases, to open directly into the abscess. These cases did not develop meningitis, because no connection was established with the uncontaminated subdural space. Brain abscesses that developed under a scalp wound in which the skull was found apparently intact were best treated in this manner. Neglected cases, or cases in which the foreign body could not be removed, or was not removed, at the first operation, could not be treated as described for the cases with no fracture, or an undiscovered fracture of the inner table, when the abscess developed at some distance from the original wound. In such instances, it was necessary to turn down a flap in order to locate the abscess. Abscesses of this type were drained through one of the openings in the skull made by the drill, using a soft rubber-tissue or gutta-percha drain.

SPINAL INJURIES

War wounds of the spine were particularly distressing. These injuries were so frequently associated with chest and abdominal wounds of a serious nature that one scarcely knew where to begin, if to begin at all. In the forward hospitals, cases in which a transverse lesion was suspected were not

operated upon. These, complicated by serious wounds of the chest and abdomen, were considered inoperable. Of the operable cases, those of the bony spine, compression of the cord, and partial lesion of the cord, were the only ones which held out a little hope of benefit from surgical interference.

Fractures of one or more spinous processes and laminæ were common in wounds entering from the back. Wounds of the spine and cord in which the shell fragment or bullet entered from the front rarely caused fractures of the vertebræ in perforating the bodies, unless the shell fragment was large, when the case was hopeless and inoperable. The most difficult cases to deal with were those of partial lesion of the cord in which the shell fragment or splinter entered from the front, penetrating the cord or perforating it and remaining in situ. Occasionally one end of the shell splinter would be lodged in the body of the vertebra and the other in the cord. At other times the shell fragment might be free in the canal.

Injuries in which the shell fragment or bullet struck the transverse process were accompanied by early symptoms of a transverse lesion following the injury. Some of these cases recovered spontaneously without any interference, while others developed a true transverse myelitis. Shell fragments or bullets which struck the spine and were deflected without producing fracture, caused a local contusion of the cord in some instances. Injuries of this type sometimes recovered spontaneously. The symptoms in the cases which recovered spontaneously were due to a form of concussion in which all function below the injury was suspended for a time. The finding of a Babinski reflex soon after the injury showed that a complete transverse lesion did not exist. Such a case was classified as a partial lesion.

Just what should be done for the bladder in these spinal cases was never a matter for general orders. It remained a difference of opinion whether permanent drainage, intermittent catheterization or abstention from any intervention, merely allowing the bladder to fill and overflow by dribbling, was the method most likely to forestall infection. On the whole there was something to be said for each of these procedures, but the "let alone" policy was that in general favor in the evacuation hospitals. The main object, of course, was to avoid infection if possible, for only so were the automatic lower-cord reflexes likely to be restored and thereby an automatic and periodic spontaneous evacuation of the bladder established.

For descriptive purposes wounds of the spine may be classified as follows: (1) Wounds of the bony spine without perforation of the dura or injury to the cord; (2) wounds of the bony spine without perforation of the dura, but with injury to the cord; (3) wounds of the bony spine with perforation of the dura and injury to the cord; (4) injuries to the cord without external wounds.

Cases of the first and second categories will be jointly considered, as the dura was not opened in these cases. The external wound was excised and loose bone fragments were removed. The wound was then sutured, bringing the muscle together with No. 2 or No. 3 chromic-gut interrupted sutures, and the skin closed with heavy interrupted silk sutures. When compression of the cord existed, the depressed bone or shell fragment lying on the dura, or wedged in the bone over the dura, was removed. Great care was exercised

so as not to produce further injury in relieving the compression. Shell fragments wedged in the fracture, or between the laminæ or spines, if firmly embedded, were approached from either side by performing laminectomy. In infected cases the wounds were left wide open, Carrel-Dakin tubes inserted, and the wound packed with sterile gauze saturated with Dakin's solution. No sutures were inserted.

The treatment of cases falling in the third category will be described under operations.

Cases in the fourth category were not operated upon. Collier [5] has described these as spinal concussion. Cases whose spines had been exposed to the shock of violent explosions showed numerous small subpial hemorrhages.

The results obtained in operations on wounds of the spine with injury to the cord were very discouraging, on the whole, and the mortality very high. Of 32 injuries of the cord reported by Cushing,[6] 7 were cervical, 2 were thoracic, 8 were lumbar, and 15 were not specified. Eight were inoperable and there were 23 deaths, or a mortality of 71.8 per cent; 24 were operated upon with 15 deaths, or an operative mortality of 62.5 per cent. These cases were all cared for in the forward area.

In considering records of work done in the forward area, it must be borne in mind that the surgeons were forced to labor under trying conditions, finding it very difficult at times to properly care for the wounded. It was at such times of great activity that the records were more or less incomplete. Because spine cases were usually evacuated early, if at all transportable, any following up of these cases in the forward area was thus impossible. Many of these cases undoubtedly died soon after their evacuation to the rear. It was rather common to have men with spinal cord injuries arrive dead or dying. Injuries of the spine, perhaps, formed a much larger group than those computed from hospital records would lead one to think, as the serious wounds involving the chest and abdomen in which death occurred at the front, were undoubtedly in many instances, complicated by spinal injuries.

Operation

The utmost gentleness and most extreme care should be taken in the handling of the cord. It should never be sponged or pressed upon. For the removal of foreign bodies delicate forceps should be used. Cord débris and blood should be removed by gentle irrigation with sterile decinormal saline solution. All one can expect to do is to remove foreign bodies and pulped cord substance that is free in the spinal canal, and in this manner to remove infected material and prevent infection. If this is done, one has accomplished all that is possible. Suture of the cord is a vain and harmful procedure, as the added handling produces more injury. An injured cord can be cleansed, but not restored.

Removal of Foreign Bodies

The external wound was excised down to the bony spine and loose fragments of bone removed. If the wound was directly over the spine, the excision was enlarged at either end and laminectomy performed. When the wound was on either side of the spine, the skin incision was made directly over

the spine. In separating the muscular, semitendinous, and fascial attachments from the spines and laminae, a large periosteal elevator was used. Retractors were then placed in the wound, thoroughly exposing the bony spines. The spines were removed by large bone-cutting forceps and the laminae carefully rongeured away. The spine and laminae of two or three vertebrae were removed in this manner.

The dura was first opened in the following manner: Two delicate silk sutures were placed in the dura on either side of the median line. Pulling up on these sutures, the dura was carefully incised with a scalpel. The opening was enlarged by using a pair of straight and slender-bladed scissors. As the opening was gradually enlarged, other sutures were inserted as before and used as retractors.

FIG. 27.—Method of opening dura

On inspecting the cord, if only a contusion existed, cord débris was removed as much as possible by irrigating gently with sterile decinormal saline solution without bringing the syringe in contact with the cord. In practice when bone fragments were found, the cord was first irrigated as already described, and bone fragments remaining in the cord were carefully removed by an esquillectomy or other delicate forceps, always in direct line with that of entry.

Small shell fragments embedded in the cord were removed in the same manner. Such fragments, if buried in the cord, were approached by first making an incision carefully in the long axis of the cord, preferably on its lateral aspect, severing one of its posterior nerve roots and using it as a retractor and removing the fragment from the front of the cord. This was important, as often the end of the fragment presenting itself on the anterior aspect of the cord was larger than the portion deeply buried in the cord or extruding posteriorly. In this manner further damage to the cord was avoided. Missiles of this type that penetrated the cord, but remained embedded in the body of the vertebra, presented the greatest problem for the operator. In order to free the cord from the foreign body it was necessary to sever several anterior and posterior nerve roots on one side, or on both sides, to permit lifting the cord entirely free from the firmly embedded splinter that penetrated or transfixed it. A firm hold on

the shell splinter embedded in the body of the vertebra could then be secured by using small curved rongeur forceps and extracting. If extraction was difficult several methods were found to be useful. Lifting the cord by its posterior roots, the shell-splinter was firmly grasped by the rongeur and an attempt made to deflect to one side and extract. This was not difficult unless the portion embedded in the body of the vertebra was larger than appeared apparent from the portion exposed. When found to be firmly fixed rotation on its long axis was done, having the effect of a drill, and attempting from time

FIG. 28.—Exposing cord for removal of embedded shell fragment

FIG. 29.—Exposing cord for removal of embedded shell fragment, using nerve root as tractor

to time to rock it back and forth. Great care was necessary in order not to break it, leaving a portion of it projecting into the canal. When such splinters broke off, leaving the bony canal free, they were disregarded. By perseverance and firm but gentle force the removal of such bodies was possible in most instances when it often seemed impossible. Another danger was the possibility of the rongeur slipping and striking the anterior and lateral portions of the cord, resulting in contusion. Operations on the spinal cord required greater care than the usual operations for cerebral injuries.

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CHAPTER IV

NEUROLOGICAL ASPECTS OF THE EFFECTS OF GUNSHOT WOUNDS OF THE HEAD[a]

The subject matter of this chapter is based on some general observations made in a series of 200 cases of wounds of the head, after their return to the United States, in practically all of which there were symptoms of injury to the brain. The 200 patients referred to represent practically all of the cases of this type under observation at General Hospital No. 11, Cape May, N. J., from October, 1918, to June, 1919. Of these patients, 163 suffered from wounds associated with demonstrable defects, and 13 with fractures of the cranial bones; 24 presented brain symptoms without demonstrable cranial injuries.

It may be seen that the greater majority of these patients presented cranial defects, which, with a few exceptions, were the results of gunshot wounds of the head, treated almost universally by early operation.

The associated brain injuries varied greatly, some being severe. In 68 patients the cerebral symptoms were slight or could not be demonstrated when the patients were admitted to the hospital. In 12 per cent of the cases there was no definite history or evidence of cranial injury, but either general or focal symptoms of cerebral origin following traumatisms of the head seem to justify their inclusion in this series.

SYMPTOMATOLOGY

For present purposes the manifestations of disturbed action of the nervous system have been classified into general and focal symptoms, in much the same sense that the symptoms caused by brain tumors are so classified; focal symptoms representing lesions of definite areas of the brain, and general symptoms those resulting from the effects of diffuse forces, such as concussion or pressure.

EARLY GENERAL SYMPTOMS

Among the early general symptoms of importance, according to the clinical records, and to the histories as given by the patients themselves, were disturbances of consciousness, amnesia, delirium and confusion, choked disc, slow pulse, headache, and vertigo. While obviously incomplete, these histories, considered collectively, have a certain value.

Disturbances of Consciousness

Data concerning the state of consciousness immediately following the injury were available in 132 cases. In 22 there was no loss, while in the

[a] This chapter is from "A Review of the Effects of Gunshot Wounds of the Head, Based on the Observation of Two Hundred Cases at U. S. General Hospital No. 11, Cape May, N. J.," by Lieut. Col. Charles H. Frazier, M. C., and Capt. Samuel D. Ingham, M. C. *Archives of Neurology and Psychiatry*, Chicago, 1920, iii, No. 1, 17.

remaining 110 there resulted from the injury immediate unconsciousness which lasted from a few minutes to several weeks. The period of unconsciousness, by number of cases, was as follows: Less than 1 hour, 51: 1 to 24 hours, 21; 1 to 6 days, 22; 6 days, 16.

Since there was such a wide variation in the manifestation of this symptom it is of interest to consider the factors active in its production. These factors include the degree of concussion, or sudden force transmitted to the brain by the blow; the amount of brain tissue traumatized, and the secondary effects of the injury, including hemorrhage, edema, and infection.

To facilitate the analysis the patients as a whole may be divided into three groups: (1) Those in whom there was no loss of consciousness, (2) those unconscious from a few minutes to 24 hours, and (3) those in whom this symptom was prolonged.

Group 1 included 22 patients with cranial defects who were not rendered unconscious by their wounds. Many of these had severe injuries, and 15 exhibited permanent focal brain symptoms. It is well known that a blow on any part of the head may produce unconsciousness by concussion, but it is apparent that this factor was insufficient to cause this symptom in the patients of this group. In explanation it may be suggested that the force of the injury was apparently exerted over a small area, and even when the cranial bones were fractured and the brain itself traumatized locally, the diffuse concussion must have been relatively slight. An illustration of this principle is furnished by the manner in which an egg may be broken—a quick, sharp blow producing a local fracture, while a slower but heavier blow results in extensive cracks in the shell. In the latter case the diffusion of the force is evidently greater than in the former.

Group 2 included 72 patients who were unconscious from a few minutes to 24 hours. It may fairly be assumed that cerebral concussion was the immediate cause of unconsciousness in this group, and that other factors were relatively unimportant in their effect on consciousness. Early surgical operations in many cases effected decompression, removed blood clots, pulped tissue, foreign bodies and bone fragments, and controlled infection. It is probable that the character of the wounds themselves, in some instances, had the effect of automatic decompression, thus preventing prolonged unconsciousness.

Group 3 included 38 patients who were unconscious for more than 24 hours. In many of these patients the effects of trauma (hemorrhage, edema, infection) were important factors. Several of this group, with residual focal symptoms indicating severe brain injury, had had early operations in which the dura was not opened, hence decompression was not effected. Some had deeply penetrating foreign bodies, and others severe wound infections and hernia cerebri. In this class were also included 10 patients with cranial fractures, not decompressed. Even from the fragmentary records available, the large proportion of injuries not relieved by decompression was striking in this group, injuries which must have produced severe secondary effects and high intracranial pressure. In none of the cases was there evidence that prolonged unconsciousness resulted from concussion alone. While it is at times difficult

to differentiate cases of uncomplicated concussion from those in which intracranial hemorrhage and edema are also present, it is apparent that prolonged unconsciousness resulting from simple concussion is rare. On the other hand, conditions producing increased intracranial pressure, such as hemorrhage and edema not relieved by decompression, must be considered as important factors in prolonging the unconsciousness primarily induced by concussion in head injuries.

Incomplete loss of consciousness, dazed and stuporous states, delirium, and mental confusion were common in the early histories, one or more of these conditions frequently following the period of unconsciousness or replacing it as the immediate effect of the trauma. These symptoms were regarded as results of the same factors that caused unconsciousness, concussion standing in relation to the earlier and the secondary effects of trauma to many of the more prolonged manifestations. In this connection it should be stated that definite symptoms apparently resulting from simple concussion occasionally persisted for several months.

Amnesia

Amnesia was present in practically all of the patients exhibiting the symptoms mentioned, and the memory blank frequently antedated the injury. In two instances patients who were injured in France had no memory of having been out of the United States. Those who were dazed or delirious for a long time often retained a fragmentary or dream-like memory of isolated occurrences, or of their subjective mental processes at times fantastic and curiously related to actualities.

Headache, Vertigo, Choked Disc, and Slow Pulse

These symptoms were recorded with varying frequency, and were all more or less closely related to the secondary effects of injuries.

LATE GENERAL SYMPTOMS

When coming under observation in General Hospital No. 11, two months or more after receiving their head wounds, many patients still manifested cerebral symptoms of a general character. These included loss of memory, slow cerebration, indifference, mild depression, inability to concentrate, fatigability, nervous irritability, vasomotor and cardiac instability, general convulsions, fine tremors, irritable reflexes, headache, vertigo, and restricted visual fields, but their manifestations varied in different patients as regards grouping, intensity, and persistence. Some of them were present in most of the cases of severe head wounds, many of them were present in some of the cases, and, exceptionally, a combination of these late general symptoms constituted the principal disability of the patient.

Almost without exception these symptoms diminished gradually, and ultimate recovery, apparently complete, occurred in from three to nine months after injury, where gross damage to the brain was absent. The tendency to recover from the symptoms both general and focal resulting from brain injuries of all degrees of severity deserves special emphasis. Since it is fairly well

established that regeneration does not occur in the central nervous system, it is evident that any nervous tissue may be affected to the extent of suspended function without suffering permanent damage, and recovery from the symptoms of brain lesions signifies returning function in injured but not devitalized neurons.

FACTORS CAUSING RESIDUAL GENERAL CEREBRAL SYMPTOMS

So far as could be determined the following factors were operative in causing the late general symptoms in the series of cases under discussion: (1) Loss of cerebral tissue; (2) injury to the brain without destruction of tissue; (3) cranial defects; (4) cicatrices; (5) psychoneurosis.

Loss of Cerebral Tissue

Symptoms resulting from the loss of cerebral tissue should properly be classified as focal, but these symptoms at times included intellectual impairment, or dementia, of which we have no definite knowledge in cerebral localization. Reference will be made, under the discussion of focal symptoms, to several instances in which the dementia apparently bore some relation to the location of the cerebral lesion.

Injuries to the Brain Without Destruction of Tissue

These injuries include the effects of concussion and pressure, and also those of disturbed cerebral circulation and nutrition. Although, from the standpoint of pathology, changes of this nature are but imperfectly understood, it should be emphasized that they are common and important. Most of the late general symptoms of head wounds are best explained on the basis of such disturbances. These symptoms include memory loss, slow cerebration, indifference, incapacity for sustained effort, and vasomotor and cardiac instability.

Cranial Defects

Cranial defects, particularly those large enough to permit fluctuation and pulsation, are commonly accompanied by vertigo, throbbing in the head, and a feeling of insecurity, all of which are accentuated by active exercises and bending movements of the body. Headache, on the contrary, was noticeably unusual in the patients with cranial defects.

Cicatrices

These sometimes act as irritating foci, causing nervous and reflex irritability, at times apparently precipitating general or focal convulsions. Headaches often were traced to pericranial and dural adhesions.

Psychoneurosis

As an element in the symptomatology of this series this condition was comparatively unimportant. With three or four exceptions, anxiety and neurasthenic symptoms were present only to a degree commensurate with the nature of the injury. Conversion hysteria was not encountered in any of the cases.

Summarizing briefly the general cerebral symptoms resulting from wounds in relation to the etiologic factors, they may be divided into four groups: Those due to (1) the immediate effects of the trauma; (2) the secondary effects of the trauma; (3) nondestructive injuries to cerebral tissue; (4) destructive injuries to cerebral tissue. The first two of these groups of symptoms appear early, the latter two coming into prominence as the earlier symptoms subside.

The immediate manifestations consist mainly in disturbances of consciousness and in dazed, delirious, and stuporous states, the principle causative factor being concussion.

The secondary effects of trauma (hemorrhage, edema, infection) add the symptoms of pressure to those of concussion.

Injuries to the brain tissue, not destructive in character, complicate all sorts of lesions and cause symptoms which last for weeks or months but which tend toward complete recovery. The syndrome of cerebral concussion (early disturbances of consciousness and prolonged mental symptoms including loss of memory, indifference, incapacity for sustained effort, and mental slowness) probably has its pathologic basis in changes of this character.

FOCAL SYMPTOMS

Transient Focal Symptoms

Although the records were incomplete, they indicated that a considerable proportion of the patients suffered from focal symptoms of a transitory character, which disappeared completely or almost completely within one or two months following the injuries. Symptoms of this nature are to be explained by local injuries to the brain of a degree insufficient to cause tissue destruction. Twenty-four patients gave a history of early hemiplegia which later disappeared entirely or left an insignificant remnant. In contrast, there were 60 patients with definite residual cerebral paralysis. Fourteen gave a history of aphasic disorders of a transitory character, while in 16 some degree of aphasia persisted as a residual symptom. Four patients described symptoms evidently due to cerebellar disturbance, all of which recovered entirely. In no case was there evidence of a destructive wound of the cerebellum, a fact to be accounted for by the highly fatal nature of wounds involving the posterior cranial fossa.

Data concerning early sensory symptoms were for the most part unreliable, as patients usually fail to note any but perceptual losses and are even liable to confuse motor paralysis with anesthesia. In 10 instances, however, there was a fairly consistent history of superficial anesthesia of unilateral distribution and of temporary duration.

Residual Focal Symptoms

Under this heading are considered the focal symptoms which persisted while the patients were under observation, in most cases six months or more after the injury.

Motor Symptoms

Of the entire series of 200, 60, or 30 per cent, of the patients suffered permanent motor symptoms of cerebral origin. Of these, 43 were hemiplegic,

9 were monoplegic, and 8 were paraplegic. The paralysis was of a severe degree in 10 hemiplegics and 3 paraplegics, while in the remaining 47 the residual motor disability was comparatively slight when the patients were last examined.

A striking feature of these cases was the marked degree of recovery which invariably occurred. Probably without exception the patients, immediately following the injury, were completely paralyzed in the limbs affected. Twenty of them were admitted to General Hospital No. 11 as litter patients; but when last examined they were all ambulatory and many of them had a very fair amount of function in the paralyzed limbs. Notwithstanding this improvement, there remained, in patients having destructive lesions in the motor areas, an irreducible minimum of paralysis.

The residual motor disabilities consisted of disturbances of voluntary motion of the arms and legs, and to a slight degree of the face. Complete paralysis of a limb was never permanent. The functions of motility most disturbed were those of highly specialized and intricate character. Individual finger movements were uniformly most affected; finger flexion invariably returned in some measure, but extension was weaker and in two cases failed to reappear at all. All movements involving bilateral groups of muscles were normal or showed insignificant disturbances.

Exaggeration of the tendon reflexes and hypertonicity of the muscles of the affected limbs was the invariable rule, although there was considerable variation in the degree of these conditions. Articular relaxation or increased range of movements in the joints as compared to the normal side was occasionally noted, and was demonstrable by the greater latitude of movement on passive manipulation after overcoming the hypertonicity of the muscles.

Incoordination constituted a factor in the disability of many of the paralytics, especially those showing a large measure of improvement though actual muscular strength was very fair.

Residual Sensory Symptoms

Permanent impairmant of cutaneous sensory perceptions of touch, pain, and temperature was found in only eight cases, and in none was it present as a complete hemianesthesia. On the other hand, 30 patients showed impairment of ability to localize sensory stimuli accurately, to recognize dual contacts, and to appreciate passive movement and position in the extremities. In the same patients there was disturbance of the stereognostic sense. The constant association of impaired sensory discrimination with astereognosis indicates that the latter condition may be considered as a manifestation of the former.

Sensory and motor symptoms frequently were associated in the same case, and those having sensory symptoms almost invariably had motor impairment. The converse was not true. Only 50 per cent of the motor cases had demonstrable sensory symptoms. This relationship of motor and sensory symptoms may in part be explained by the dependence of normal movement, especially its coordination, on the discriminatory element of sensation.

Residual Aphasia

In 16 patients disturbances in the use of language remained six months or more after the wounds were received. Of these, 10 were of the motor or dysarthric type, 3 of the sensory type with alexia as the most prominent symptom, and 3 were of the mixed type, manifesting disturbances both in the depression and in the interpretation of language. In none of the patients were the residual asphasic symptoms of severe degree, and all were able to carry on simple conversations fairly well. The patients with alexia were ultimately able to recognize letters and many words, but did not regain the ability to read understandingly to any practical extent.

Residual Visual Symptoms

Cerebral wounds were associated with defects in the visual fields in 18 cases, 12 of which were more or less complete homonymous hemianopsia, 3 were quadrant anopsias, 2 were symmetrical paracentral scotomas, and 1 was almost completely blind. Comparatively slight improvement was noted in the vision of these cases during the period of observation.

Mental Symptoms

The occurrence of mental disturbance has been mentioned in connection with the general symptoms of cerebral injuries. Aside from the mental symptoms of cerebral concussion and the mild dementias of indeterminate type associated with many brain injuries, a few of the patients showed late psychic symptoms which evidently resulted from cerebral wounds, and apparently bore some relation to the injured areas of the brain. This was true in four cases in which penetrating wounds involved both hemispheres. In three of these both frontal lobes were affected, and in the fourth a foreign body entered the right frontal region, penetrating to the left posterior parietal region near the cortex. Mental symptoms were pronounced in all of these patients and consisted of disorientation, loss of memory, emotional indifference and disregard of environment and personal appearance. In some measure they resembled the simple dementia of general paresis. Of the many patients with unilateral frontal lesions, some of them extensive, none showed characteristic psychic symptoms. These circumstances indicate the seriousness of bilateral brain lesions, and suggest the theory that either cerebral hemisphere may functionate in a way to minimize the effect of a lesion in the other.

Convulsions

Convulsions occurred in 28 patients, either before admission or while under observation at General Hospital No. 11. In 4 of these the attacks were focal without general involvement, 11 had local spasms initiating general attacks, and in 13 the convulsions were general so far as observations were recorded, although it is probable that some of these were preceded by unobserved focal symptoms. Attacks were observed in patients having lesions in the motor area and hemiplegia in which focal signs were definitely absent.

In 3 of the cases of this group it was found that attacks had occurred prior to military service, leaving 25 in which there was evidently a close relationship between the war wounds and the convulsions. In 22 of these the wounds

involved the parietal region, and in 21 there was motor paralysis. In the remaining 3 cases the wounds were in the frontal, occipital, and temporal regions. It is thus apparent that not only focal but general convulsions were associated with motor areas of the brain in the great majority of the cases, and that irritation of these areas is more productive of general convulsions than of other parts of the cerebrum.

Eighteen of the twenty-five patients were free of attacks for several months prior to the cessation of the period of observation; three others had but a single attack each. Four had repeated convulsions over a prolonged period, thus evincing a tendency to chronic epilepsy; these were all hemiplegic, and the attacks were the type which begin as focal convulsions, then become general with loss of consciousness.

The most frequent period for the occurrence of the attacks was soon after the wound had been received or after some operation on the head. About one-half of this group of patients had isolated convulsions at such times without later recurrences.

It should be stated that, as a routine measure, bromides were given in 10-grain doses three time a day to all patients having convulsions and to all those subjected to operations on the head, a measure which no doubt reduced the incidence of the attacks while the patients were under observation.

PATHOLOGY

The degree of injury to the brain varied from insignificant lesions to extensive losses of cerebral tissue. In 23 cases intracranial foreign bodies were demonstrated by the Roentgen ray, some of them having almost traversed the cranial cavity. Small, indriven fragments of bone were common and were usually located in the vicinity of the cranial defect. In 26 cases the wounds were unhealed on admission, most of these having sinuses extending beneath the dura to fragments of dead bone or foreign bodies. One patient, who died four days after admission, had a large temperoparietal abscess and hernia cerebri. This patient was one of the two fatalities in the entire series of head wounds at General Hospital No. 11. The second fatality resulted from a complicating pneumonia and internal hydrocephalus, occurring after the wound had healed and the patient was convalescent.

During cranioplastic operations evidences of cerebral injury were at times noted. In such operations the dura was not usually opened, but occasionally it was necessary and several times in this way cystlike cavities filled with cerebrospinal fluid were exposed. In one notable case of this kind the operating surgeon opened such a cavity in the occipital lobe which communicated with the posterior horn of the lateral ventricle.

In estimating the area and extent of the cerebral lesions resulting from war wounds it may be stated as a rule that, in the absence of penetrating foreign bodies, the area of destruction of brain tissue conforms quite closely to the cranial defect, and extends but a few centimeters beneath the cortex. Foreign bodies may penetrate to almost any part of the cerebrum, even traversing the ventricles without causing death. The course of foreign bodies can be estimated by careful Roentgen-ray studies, comparing their location with the wound of entrance.

TREATMENT

Besides the surgical treatment, special courses of treatment were given to practically all of the patients with the object of increasing their general efficiency, and of reducing to a minimum the effect of the disabilities from which they suffered. School, occupational, and workshop courses were prescribed, according to conditions.

Patients with hemiplegia and paraplegia received daily treatments consisting of special massage, passive movements, and electricity, also active exercises, employing the affected limbs to a maximum extent on gymnasium apparatus, and in recreational exercises in which handballs and footballs were found to be especially valuable. The results of this treatment were evident in reducing the spasticity and preventing contractures in paralyzed muscles and in procuring a maximum return of function. The training of the unaffected muscles to compensate as far as possible for those of impaired function gave the patients greater freedom of action, and the general poise, self-confidence, and morale were noticeably improved.

Aphasics constituted another group that received special attention. Trained teachers gave the members of this group daily individual instruction and exercise in conversation, reading, and writing adapted to the needs of the patient and the character of his language disturbance. Although no evidence of the development of new language centers on the normal side of the brain was seen, improvement was marked in every patient of this group, the aphasic symptoms of some of whom had previously remained stationary for several months.

CHAPTER V

LATE TREATMENT OF GUNSHOT WOUNDS OF THE HEAD

The surgery of gunshot wounds of the head in the secondary stage of treatment followed, for the most part, lines which had been determined prior to the outbreak of the World War. It is true that a greater zeal was shown during the late reconstruction period in the restoration of portions of the skull than was apparent in the management of cranial defects in civil life, but with this exception, the late treatment of head wounds offered a limited field for surgical procedures.

Destructive brain injuries and late pathological conditions resulting from intracranial hemorrhage and from contusion of brain tissue, while presenting neurological problems of great interest to the surgeon, rarely required operation. A review of the late surgical treatment of head wounds deals almost entirely with the following conditions: Cranial defects, brain abscesses, retained foreign bodies, and epilepsy.

CRANIAL DEFECTS

Prior to the World War there was considerable discussion as to the benefits to be expected from the repair of cranial defects. Symptoms which during the secondary period of treatment were attributed to a loss of portions of the cranial bone, previously had been regarded by many authoritative observers as arising from the associated damage to the brain tissues. The study of a large number of cases of cranial defects led to the rather general belief that the loss of bony protection of part of the brain may be accompanied by disturbances due to the opening itself and that the disability of a patient with serious brain damage associated with cranial defect may be reduced by a restoration of the bony loss.

The repair of cranial defects was the most frequent surgical procedure in the treatment of head wounds during the reconstruction period of the World War injured; in fact, with the exception of relatively few operations for abscesses and for retained foreign bodies, cranioplasty was practically the only operation performed upon the skull. Some idea of the frequency of cranial defects may be obtained from a series of 200 head cases at General Hospital No. 11, Cape May, N. J., reported by Frazier and Ingham.[1] In this series, 163 patients had cranial defects.

Projectile wounds of the skull present a rather characteristic appearance. Usually, an area of the scalp as well as bone has been lost and in many cases a long-continued infection has added to the extent and density of the resulting scar. These scars are subject to trophic disturbances, often with ulceration and mild infection many months after apparent healing. As a rule the bony opening is irregularly quadrangular, although triangular, circular, and narrow

FIG. 30.—Conspicuous craniofacial defect with dense scar

FIG. 31.—Large right parietal defect. Photograph shows model and location of defect. Repair by autogenous cranial transplant after Frazier's method

FIG. 32.—Characteristic defect in the parietal region

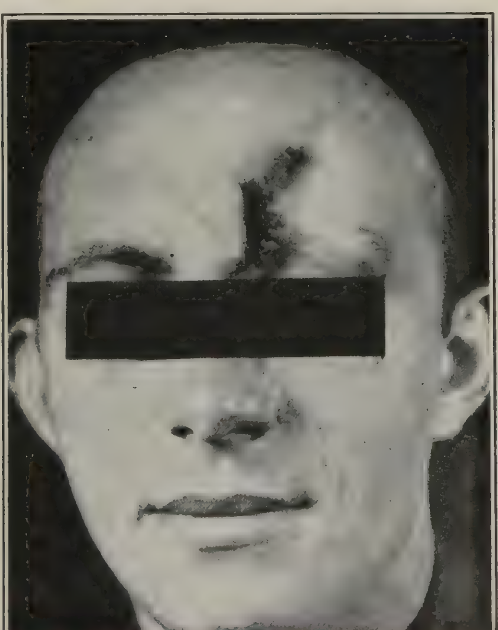

FIG. 33.—Characteristic defect in the frontal region

linear defects caused by tangential wounds are seen. In defects of moderate or large size without intracranial tension, when the patient's head is higher than the body, the skin overlying the defects recedes sometimes to considerable depth. On the other hand, the skin overlying the defect becomes level with the surrounding scalp or protrudes when the patient lies down or stoops. It is this fluctuation of the defect which seems to be mainly responsible for the patient's symptoms. The usual complaints are of throbbing and pulsation about the defect, vertigo upon exertion, a feeling of insecurity and particularly a dread of injury to the unprotected brain. Any sudden change of position such as stooping, a sudden movement of the head, or coughing, may be followed by one or more of the symptoms. The patients are fairly comfortable when quiet, though sleep is sometimes disturbed because of the throbbing or vertigo when lying in bed; they suffer from the exaggeration of symptoms upon exertion. Tenderness of the scar and over the rim of the defect is frequently complained of. Fluctuation of the defect is thought by some to produce tension on the adhesions connecting the overlying scalp with the brain and with this fluctuation there may be sudden changes in the blood supply of the brain adjacent to the defect.

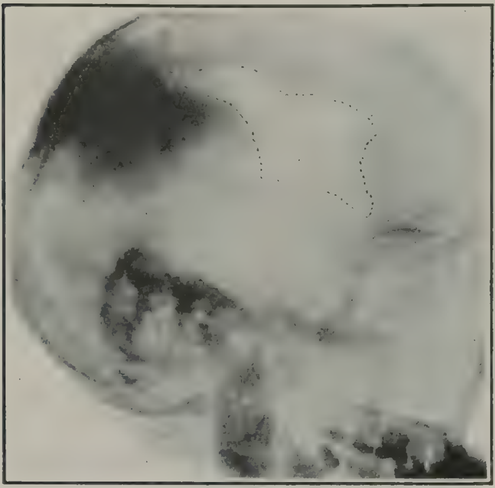

FIG. 34.—Skiagraph of an irregular defect in the parietal region

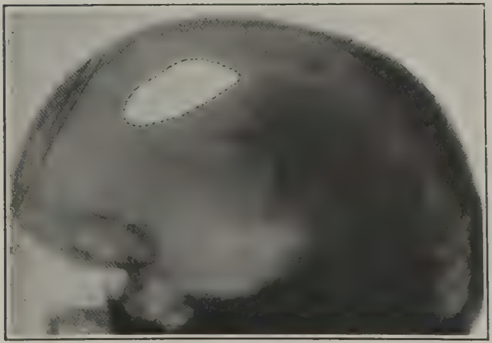

FIG. 35.—Skiagraph of a characteristic oval defect in the frontal region

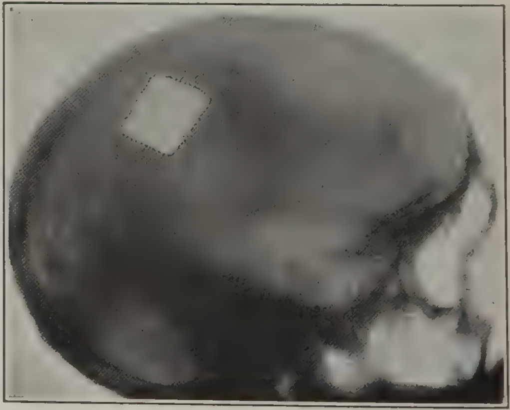

FIG. 36.—Skiagraph of a rectangular defect, in the parieto-occipital region, resulting from removal en bloc of area of skull in débridement

Often defects are very conspicuous deformities, in which case an operation is required not only for its protective value but also for cosmetic reasons;

FIG. 37.—Large parietal defect. Roentgenogram before cranioplasty

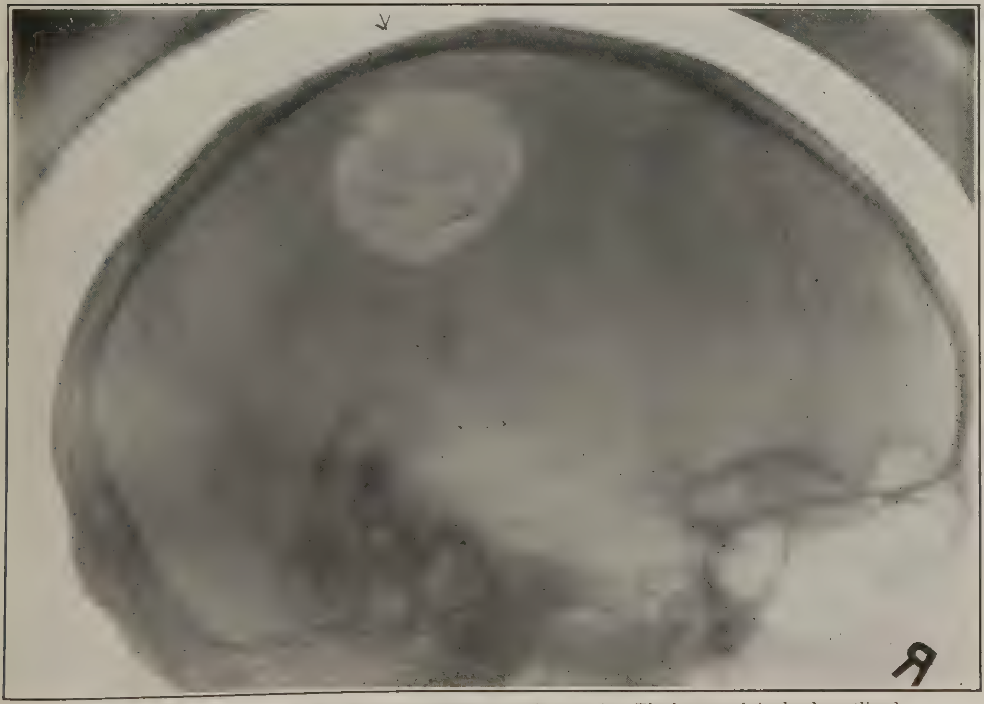

FIG. 38.—Roentgenogram of head shown in Figure 37, after repair. The bone graft is clearly outlined

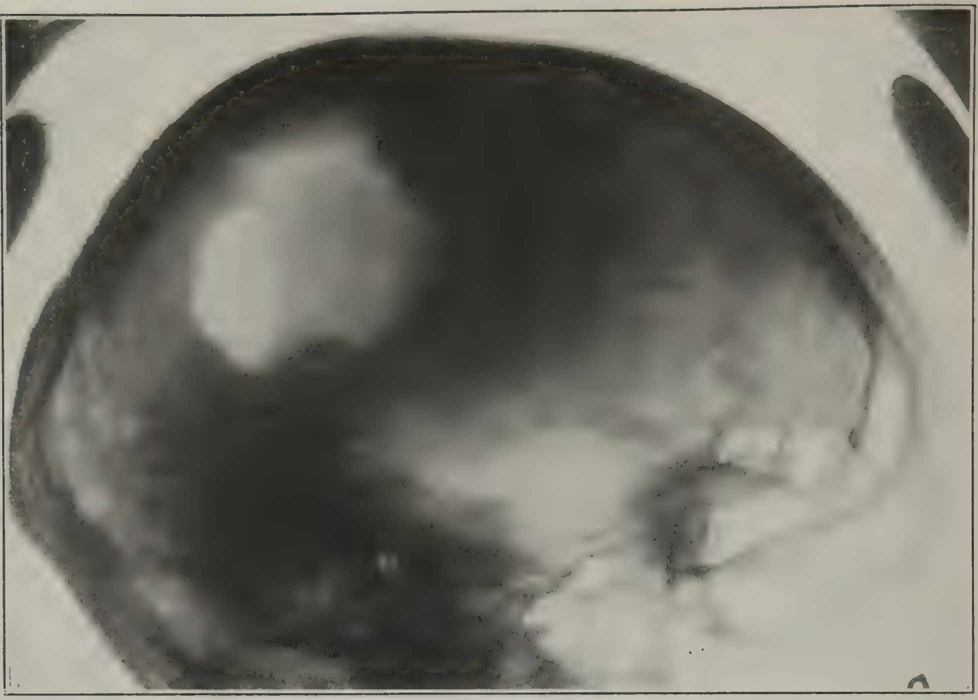

FIG. 39.—Posterium parietal defect. Roentgenogram before cranioplasty

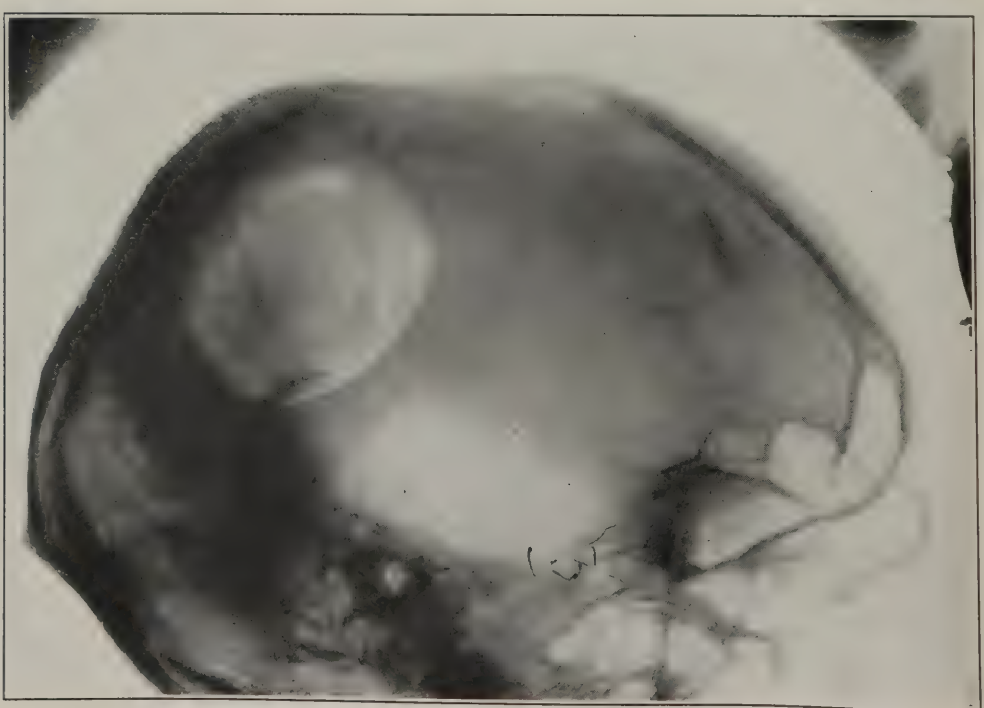

FIG. 40.—Roentgenogram of head shown in Figure 39, after autogenous cranial transplant

however, in the zeal for the restoration of lost bone certain contraindications to a cranioplasty should not be overlooked. The operation should not be done for war injuries until there is a reasonable certainty that infection has been removed from the tissues. This removal of infection requires from three to six months after all gross evidences of infection have disappeared. Any associated intracranial process accompanied by an increase in tension, the presence of large intracerebral foreign bodies, and sometimes epilepsy, make an operation inadvisable.

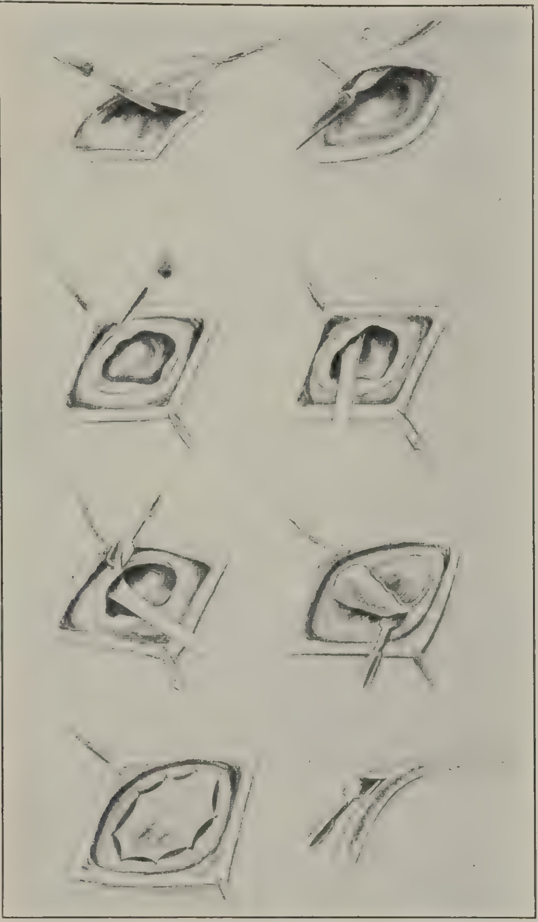

Fig. 41.—Consecutive stages of operation. (1) Excision of scar from defect. (2) Exposure of rim of defect by incision through scar. (3) Incision through pericranium about a quarter of an inch from the edge of the defect. The purpose of the incision is to provide for bone contact with the graft and to free the adherent dura. (4) The pericranium within the incision (3) is forcibly displaced within the defect by an elevator. Adhesions of the dura to the edge of the bone are thus freed. (5) Beveling the edge of the defect for contact with the graft. The dura is carefully protected by a thin spatula. (6) Removal of the transplant from the parietal eminence. The size and shape of the transplant have been modeled by rubber dam and the graft cut to fit accurately. (7) Shows graft partly sutured by uniting the pericranium of the graft with that surrounding the defect. (8) Cross section of graft. (Coleman)

Medical literature pertaining to the period of the World War abounds in descriptions of the technique of cranioplasty and much surgical ingenuity was displayed in its performance. Of the materials which had been used to replace lost bone, metal, rubber, and celluloid plates, animal transplants, homotransplants, and autogenous grafts from the skull, tibia, scapula, and ribs, were recommended; however, with the exception of autogenous grafts and celluloid plates, these materials, to a large extent, have been abandoned. Autogenous grafts came to be the material of choice in most of the hospitals, with the occasional use of celluloid plates for large defects. Wegeforth, by animal experiments at the Army Neurosurgical Laboratory, Johns Hopkins Medical School,[2] showed that the cranial transplant possessed great advantages in repair of defects of the skull. It was also demonstrated clinically that the autogenous cranial transplant possessed similar advantages, and that a graft of any desired shape may be easily obtained,[3] whereas grafts from the tibia or ribs are more likely to leave an uneven surface following the transplant. The molding of rib or tibial grafts to conform to the curve of the skull is often difficult and it

is not unusual to find irregular depression over such transplant after firm healing.

The technique of applying the autogenous cranial graft varied somewhat. Frazier [1] recommended the application of the graft with its bony surface toward the brain (fig. 41) whereas other surgeons, notably Bagley,[4] after hinging the graft on one of its pericranial borders, applied it with the bony surface in contact with the scalp.

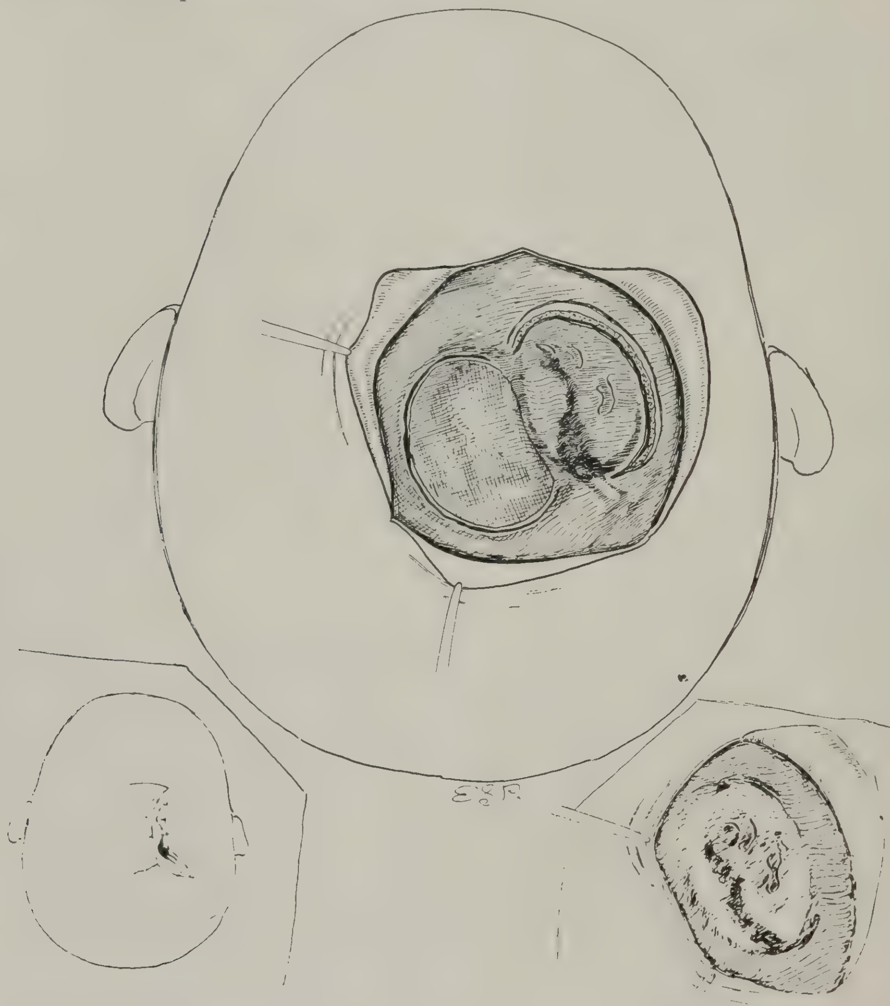

FIG. 42.—This and Figure 43 illustrate Bagley's hinged flap method. The scar has been excised, the flap reflected, and the graft outlined on the skull adjacent to the defect

The preparation for the application of the graft is begun by removing the scar tissue from the scalp by means of an incision which follows the lines of the old scar. The dura is freed from the bony rim, which then is beveled with a fine chisel. Foreign bodies and spicules of bone, if accessible, are removed, but the dura is not usually opened, though it might be stated parenthetically that, in a few head injury cases, traumatic cysts of considerable size were

found beneath the defect. The graft from the skull is cut by a pattern of the defect made from rubber dam or muslin. A favorite site for obtaining the graft is the region of the right parietal eminence, though in cases with large defects it is often necessary to take the graft from the opposite side of the head. By means of a small chisel the pattern of the defect is outlined on the bone

FIG. 43.—The osteoperiosteal graft has been raised and hinged on the pericranial border which lines one side of the rim of the defect. The drawing shows suture of the graft in position, with its bony surface in contact with the scalp

from which the graft is to be obtained and a thin layer of the outer table is removed with its overlying pericranium. The transplant usually curls toward its periosteum during removal and resembles a thick fish-scale mosaic with the bony fragments held in contact by the pericranial covering. The graft is molded into the desired curve by pressure and placed upon the defect with its

bony surface in contact with the dura. Fixation is secured by fine interrupted silk sutures uniting the pericranium of the graft with that around the edges of the defect. The wound is closed in layers, with rubber tissue drains beneath the scalp covering the transplant to the area from which the graft is taken. Confinement to bed for two weeks in a horizontal position favors a proper curve of the thin transplant and allows it to "set" on a plane which conforms to the contour of the surrounding skull.

It is not necessary that the thickness of the graft be equal to that of the outer table. Studies of bone regeneration show that the osteogenetic activity resides in

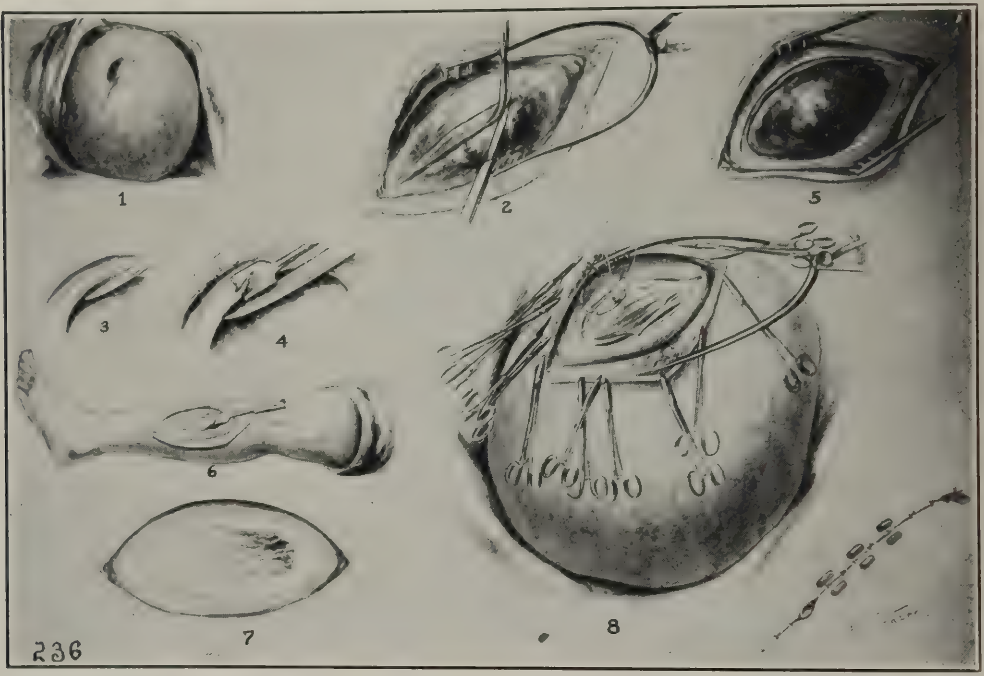

Fig. 44.—Cranioplasty by transplant from tibia (King). (1) Site of defect, showing line of incision. (2) Scalp flaps. dissected up, held with self-retaining retractor, and excess of scar tissue overlying dura excised. Incision is made through pericranium ¼ inch from margin of defect. (3) The dura is freed from the bony margin with elevator. (4) Bony margin is freshened and beveled with an osteotome, while the dura is protected with a hollowed brain retractor. (5) Pattern cut from muslin to fit the defect, the site of which is now ready to receive the transplant. (6) Removal of periosteal-bone transplant from tibia (should be internal surface). (7) Bony surface after removal of transplant. (8) Suture of transplant into position, periosteum to pericranium. (9) Suture line; the two small rubber drainage tubes, which are removed after 48 hours

the periosteum and superficial layers of the underlying bone; autogenous cranial transplants show satisfactory bone proliferation and generally give a firm protection without depression or ingrowing spicules. Since cranial bones heal without cartilage production, this fact gives advantages to the cranial transplant over those from the long bones; in many cases it is very difficult to discover without X-ray examination, the location of a defect a month or six weeks after operation, and the permanency of the results has been shown by the firm protection of the defect after a number of years. The hinged graft with the pericranium applied to the brain is thought by some to have a better nutrition, to give a smoother surface for contact with the brain covering, and to furnish

a better contour than grafts in which the surfaces are reversed with the pericranium in contact with the scalp.

Linear defects are well suited to tibial transplants. The method of removing these transplants has been repeatedly published.

Many of our World War injured, with cranial defects, had chronic sinuses of the scalp. In the treatment of these sinuses minor surgical procedures were generally useless, for further exploration of all the infected tracts with removal of dead bone and foreign bodies is usually required before infection is eradicated; however, the use of Dakin solution greatly aided the removal of these superficial infections.

Fig. 45.—Cranial defect in right parieto-occipital region following loss of osteoplastic flap. Photograph shows necrotic flap and infected wound. Plastic operation on scalp, after infection subsided, preceded cranioplasty

Fig. 46.—Roentgenogram showing osteomyelitis of osteoplastic flap and outline of bony defect

In some of the patients, after healing of the scalp had taken place, extensive scars remained overlying the defect, and excision of the scars interfered with closure of the skin over the bone grafts. Improved results were obtained in such cases by doing first a plastic operation upon the scalp so as to cover the defect with healthy skin, reserving the cranioplasty for a later operation. The tension of the scalp not only interferes with wound healing but also tends to flatten and depress the transplant, thus preventing a good cosmetic result, although the defect may be firmly protected.

Preference is properly given to autogenous transplants; there are cases, however, of large cranial defects in which the use of celluloid plate gives better results. The major part of the operation for the application of an autogenous transplant consists in making the graft, whereas the preparation of the defect is usually a minor part of the procedure. While the repair of the defect by any of the methods involves slight risk and the autogenous method is almost uniformly satisfactory, the operation is quite a considerable procedure in a

few cases with large defects. There also tends to be some sagging of a large repaired defect of the vertex where autogenous material is used. Ney[a] prefers the celluloid plate for all cases and feels that the cosmetic result and the relief of the trephine syndrome are all that could be desired.

Most of the cranioplasties performed on our World War injured were done under general anesthesia, but local anesthesia may be used satisfactorily, and it has the advantage of lessening the blood loss.

The improvement in patients who have had defects repaired by the methods described is very striking. Even though destructive lesions of the brain can not be benefited by restoration of the bony covering, in many cases epileptic seizures were reported to be greatly diminished in frequency. Aversion to physical exercise generally disappeared; the discomforts arising from pulsation, throbbing and dizziness on sudden movement was relieved or improved and the patient was enabled to undertake a physical reeducation with greater optimism.

ABSCESS OF THE BRAIN

The principal cause of death in patients with head wounds, after their return from overseas, was brain abscess. It is difficult, if not altogether impossible, to form an idea of the total number of late abscesses which followed wounds of the head. Among 1,111 head cases in the World War whose clinical records were studied with a view of determining late results, operations for abscesses were reported on 11 patients.[5] This percentage of abscesses might be considered as fairly representative of the number which actually developed.

Abscess from head injury was generally found in cases in which there were retained foreign bodies. In these patients the difficulty of removing metallic foreign bodies or fragments of bones at the primary operation was too great to be overcome.

Encapsulated abscess of war wounds presents practically the same problems as are encountered in the management of abscesses resulting from a spread of infection from the sinuses. It was found, however, that when a missile or bone fragment had traversed a wide area of brain tissue, particularly of the motor cortex, and a tubular abscess of a silent region resulted, the difficulties of diagnosis and treatment were enormously increased. In the large majority of cases the retained foreign body was quiescent and the healing was prompt. Particularly was this true if the primary operation had completely removed the bone fragments and other organic débris. In some cases a sinus persisted with incomplete drainage of the abscess cavity which either inclosed or lay in proximity to a foreign body.

Brain abscess did not appear to be a very frequent complication of the superficial infections with sinus formation of the scalp and skull. Cases in which abscess formed usually had an infection of the brain tissue itself and the eradication of this infection at the primary operation had been unsuccessful; the onset of symptoms of the abscess appeared in some cases many months after the healing of the wound. In others the drainage from the sinus persisted a number of months before signs of an intracranial complication became mani-

[a] Personal communication

fest. In a few cases the abscess was unexpectedly encountered during the operation for the removal of a foreign body which was presumed to be quiescent.

The following pathological observations on brain abscess are based on Bagley's [6] study of head injuries among members of the American Expeditionary Forces.

BEHAVIOR OF THE BRAIN WITH REGARD TO THE FORMATION OF THE ABSCESS WALL AFTER THE INTRODUCTION OF INFECTION

The wall of the abscess is the most important factor in determining the outcome of well-managed brain abscesses. As in all other inflammatory lesions the wall formation depends first upon the type of infecting organism, one of low virulence causing a more gradual accumulation of pus than one of greater virulence thus allowing sufficient time for the protective reaction of the tissue. The resistance of the infected tissue is important. This protective reaction takes place principally in two kinds of tissue, fibrous mesoblastic and glial epiblastic. The fibrous tissue is far more effective but, unfortunately, is almost unavailable in the deep substance of the brain where glial tissue must suffice. In addition, it is influenced by the method of infection.

Abscesses of long duration may have walls of greater thickness, but it is more likely that the duration is long and the wall thick because of the character of tissue available for proliferation.

TYPES OF ABSCESS WALL

The following are types of abscess wall: Type I.—Dense fibrous mesoblastic tissue wall. Type II.—Fairly firm wall, containing some fibers proliferated from neighboring mesoblastic tissue. Type III.—Walls of varying thickness the result of glial proliferation. Type IV.—Walls showing no evidence of a protective reaction.

Dense Fibrous Mesoblastic Tissue Wall (Type I)

If fibrous tissue is available for the abscess wall, it takes first place in the formation of the protective membrane. The meninges, constituted largely of fibrous tissue, act as a barrier to pus (as in extradural abscess formation) and may furnish tissue for active proliferation and the walling-off of infection, even though the membranes be severely traumatized. Figures 47 and 48, for example, show the result of proliferation after a smashing skull injury. Figure 47 shows the firm wall abscess removed from W. F. M. in cross section. Figure 48, a photomicrograph, shows the wall to be made of mesoblastic fibrous tissue.

A very unusual reaction of the dura appears in Figures 50 to 54, photomicrographs of a large abscess of four months' duration, which was confined entirely within the limits of the dural tissue. In Figure 50 the firm fibrous tissue wall was the result of proliferation of the slowly distending dura. Figure 51 shows adult fibrous tissue strands and young fibrous tissue elements in this same abscess. Figure 53 shows the tensile quality of the fibers constituting

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FIG. 47.—Cranial abscess. *a*, Bone fragments at center of abscess; *b*, fibrous tissue abscess wall and site of section shown in Figure 48

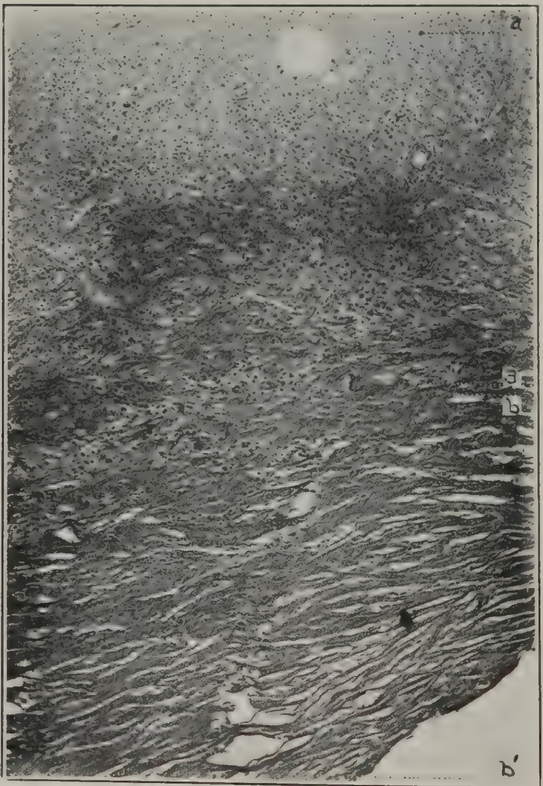

FIG. 48.—Section of wall from *b* in Figure 47. *a* to *a′*, inner layer of abscess wall, showing young fibrous tissue elements; *b* to *b′*, outer layer of abscess wall, showing adult fibrous tissue. ×85

FIG. 49.—Pedunculated dural abscess. *a*, Abscess stalk, point of attachment to dura; *b*, layer of cerebral tissue adherent to abscess; *c*, fibrous tissue wall of abscess; *x*, site of section shown in Figure 50; *y*, site of section shown in Figure 53

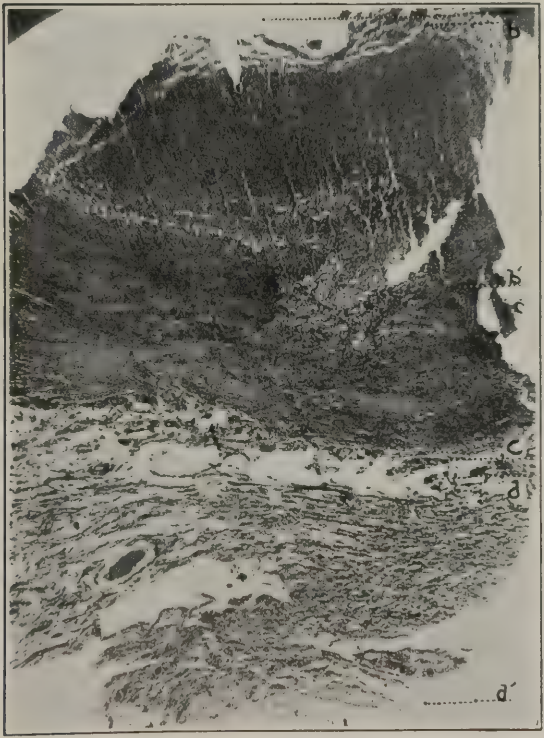

FIG. 50.—Section at *x* of wall of abscess shown in Figure 49. *a*, Abscess cavity; *b*, necrotic tissue covering inner surface of abscess wall; *c*, abscess wall, shown also in Figure 51; *d*, brain tissue, the site of active glial proliferation. ×15

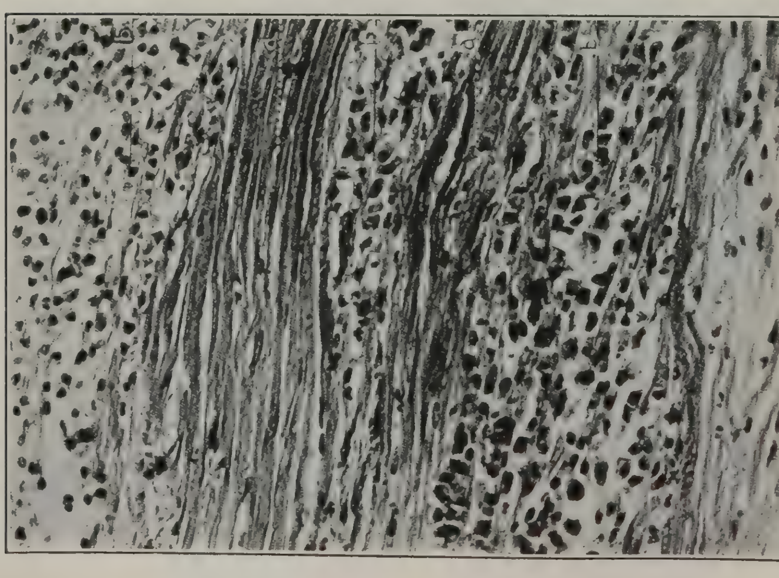

FIG. 51.—Higher magnification of a section from *c* in Figure 50. *a*, Adult fibrous tissue strands; *b*, young fibrous tissue elements. ×325

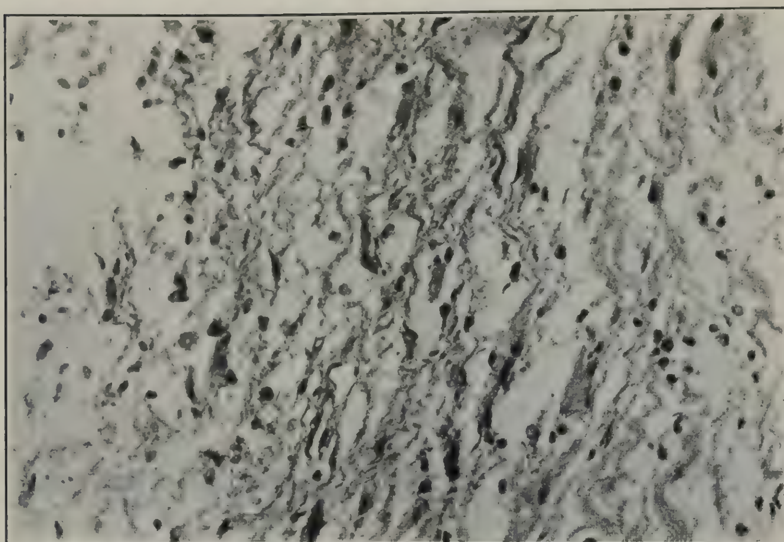

FIG. 52.—A higher magnification of *d* in Figure 50, showing neuroglia fibrils. ×325

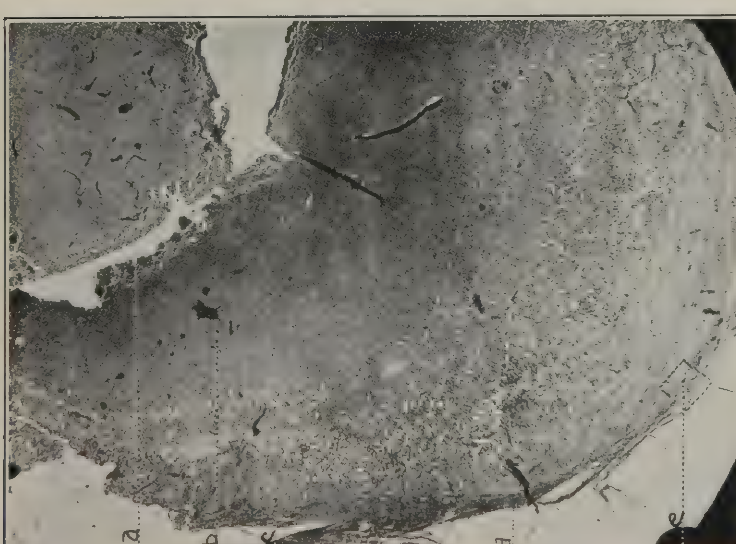

FIG. 53.—Section at *y* of wall of abscess shown in Figure 49. *a*, Abscess cavity; *b*, necrotic substance covering inner surface of wall; *c*, young fibrous tissue elements; *d*, adult fibrous tissue; *e*, site of section shown in Figure 54. ×15

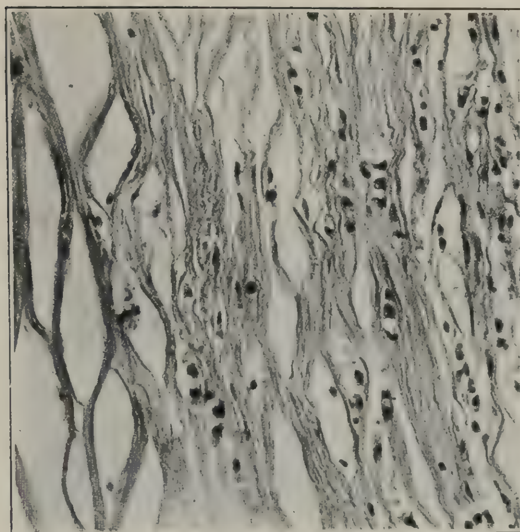

FIG. 54.—Higher magnification of section at *e* in Figure 53, showing firm fibrous tissue strands. ×300

the wall of the abscess, for a few strands were sufficient to protect the abscess against rupture. The quality of these strands is shown in Figure 54. Beyond the fibrous tissue wall there was neuroglial proliferation, as shown in Figure 52. This latter reaction of cerebral tissue, of little importance in this case, is the main protective reaction in the wall of the abscess designated as Type III herein.

It is evident that the method of infection and the propinquity of mesoblastic tissue to the site of infection influence greatly the above-described formation of an abscess wall.

Fairly Firm Wall Containing Some Fibers Proliferated From Neighboring Mesoblastic Tissue (Type II)

The type of abscess wall shown in Figure 56, while not the most valuable, represents the usual form of reaction when the infection occurs deeper than the fibrous tissue coverings. The chief reaction takes place in the glia, but this is augmented by proliferation from the mesoblastic elements of the blood vessels. In addition to the availability of the mesoblastic tissue, the quality of the resulting

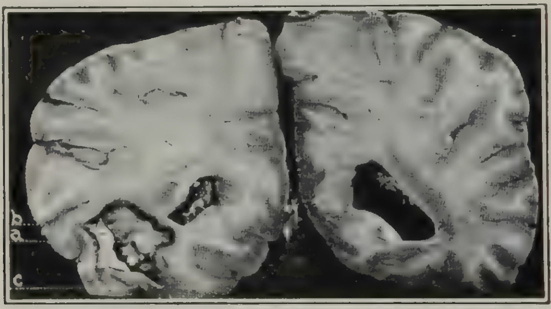

Fig. 55.—Frontal section of a brain with left temporal lobe abscess. *a*, Abscess cavity; *b*, abscess wall and site of section shown in Figure 56; *c*, site of section shown in Figure 57

wall is likely to improve somewhat with the duration of the process. In specimens under consideration all of which were of less than a year's duration, the fibrous tissue proliferation reached a stage in no sense approximating the density of the wall shown under the heading of Type I. In Figure 58 the small band of fibrous tissue represented the most advanced stage of the fibrous tissue proliferation of an abscess wall which had existed as long as the wall shown in Figure 47. Hassin,[7] however, described a wall of eight years' duration in which the outer layer of the abscess wall was made up of adult fibrous tissue strands.

The question of time necessary for the proliferation of an abscess wall is an important one. It is certainly unusual for an abscess to exist for a period longer than a few months and walls of this type may be formed with great rapidity, the history of the abscess shown in Figure 56 indicating that the wall was formed within a period of three or four weeks. The hemorrhages shown in Figure 57 were no doubt due to the very active vascular proliferation in the soft cerebral tissue.

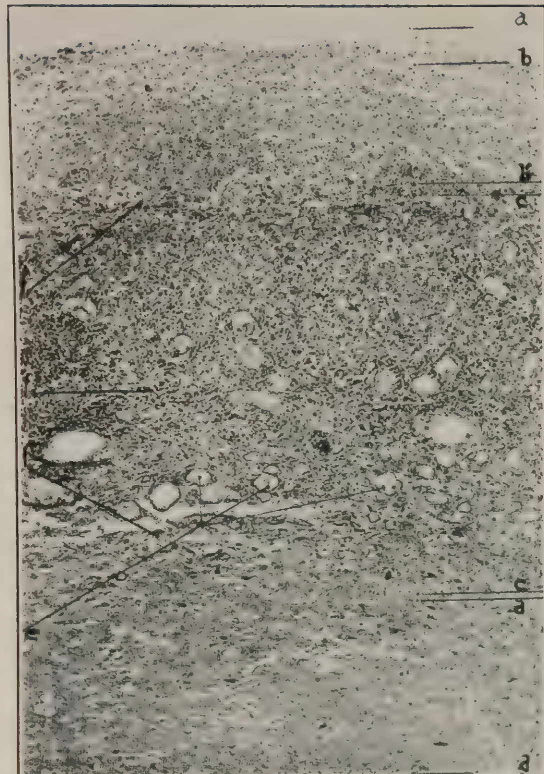

FIG. 56.—P. V. A section from *c* in wall of abscess shown in Figure 55. *a*, Abscess cavity; *b* to *b'*, necrotic substance on inner surface of abscess wall; *c* to *c'*, abscess wall; *d* to *d'*, brain tissue; *e*, thin wall blood vessels; *f*, framework of abscess wall consisting chiefly of fibrous tissue proliferated from the blood vessels. ×85

FIG. 57. P. V. A section from *b* in wall of abscess shown in Figure 55. *a* to *a'*, Inner layer of abscess wall; *b* to *b'*, hemorrhagic extravasation in abscess wall; *c* to *c'*, outer portion of abscess wall, showing extensive vascular proliferation and numerous punctate hemorrhages. ×85

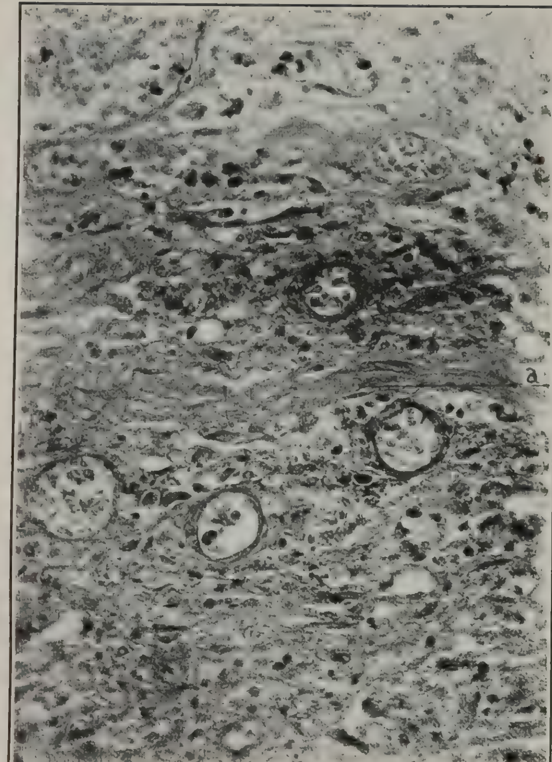

FIG. 58.—Section from an abscess wall similar in type to that shown in Figure 56 but of longer duration. *a*, Small band of adult fibrous tissue. ×325

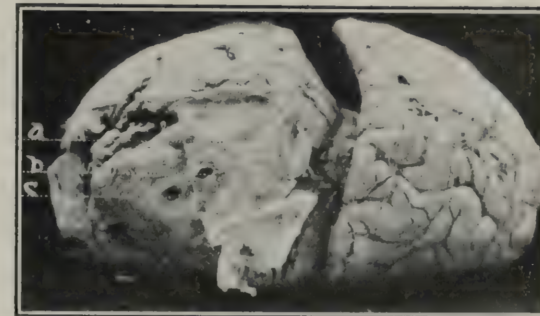

FIG. 59.—Frontal view of brain, with large abscess in right frontal lobe. *a*, Adherent dura of frontal lobe reflected toward mid line; *b*, perforation of dura; *c*, perforation in frontal lobe, which was continuous with *b* and formed the abscess stalk

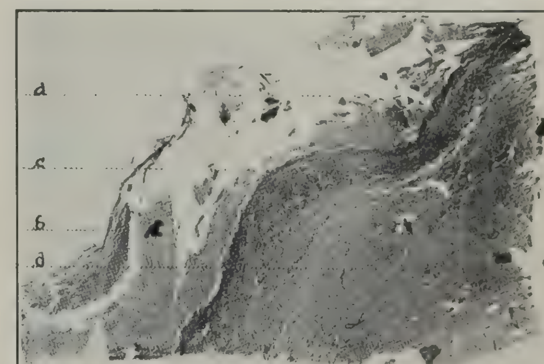

FIG. 60.—L. F. A section from the wall of the abscess shown in Figure 59. *a*, Abscess cavity; *b*, disorganized tissue of inner abscess wall and site of section seen in Figure 61; *c*, abscess wall; *d*, brain tissue adjacent to the abscess wall. ×6

Walls of Varying Thickness, the Results of Glial Proliferation (Type III)

Walls formed almost entirely of glial fibrils may be very heavy, but because of the delicate character of the fibrils the wall is not so resistant as one in which there is fibrous tissue. In Figure 60 the wall visible microscopically and in this picture of low magnification has the appearance of a thick, limiting membrane, but the delicate quality of the tissue is shown in Figure 61. The relative value of this type and of the firm fibrous tissue wall is perhaps best shown in

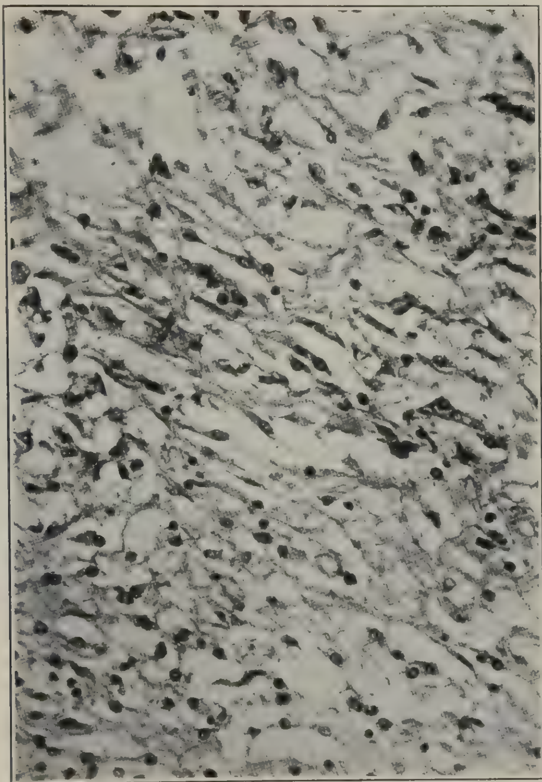

Fig. 61.—L. F. A higher magnification of wall of abscess seen in Figure 60, showing the membrane to consist of delicate fibrils. ×325

Figure 50, in which there is a firm fibrous tissue wall at *c* and at *d*, the adjacent cerebral tissue with glial proliferation. A photomicrograph of *d*, given in Figure 52, is similar to the abscess wall shown microscopically in Figure 61.

The neuroglial fibrils are again well shown in Figure 62, which was taken from the innermost part of the abscess wall. A large part of the cellular element has fallen out because of the necrosis, leaving the fibrils in plain view.

Walls Showing No Evidence of a Protective Reaction (Type IV)

Figure 64 shows an abscess which was the result of a virulent streptococcus planted deep in the substance of the cerebellar hemisphere. There is no evidence of a protective reaction and the lesion marks an intermediate stage between

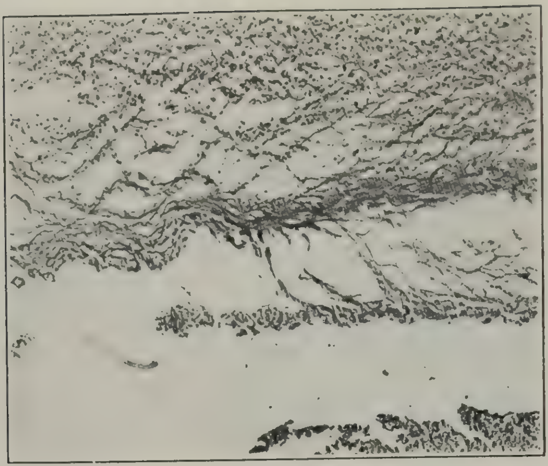

FIG. 62.—L. F. Section of the innermost portion of abscess wall in Figure 60. Because of the necrosis the cellular elements have fallen out, leaving the delicate fibers in plain view. ×85

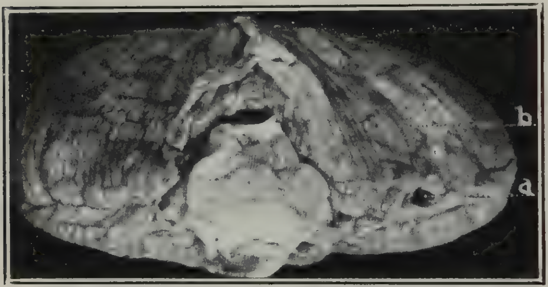

FIG. 63.—Upper surface of cerebellum, with abscess in left hemisphere underlying *b*. A cross section of the abscess is shown in Figure 64. *a*, Point of spontaneous evacuation of abscess into posterior fossa

FIG. 64.—Cross section of cerebellum seen in Figure 63. *a*, Abscess cavity; *b*, area of hemorrhagic extravasation, the result of thrombosis; *c*, site of section shown in Figure 65; *d*, site of section seen in Figure 66

an encephalitis and the usual abscess formation, for though suppuration occurred there was no true barrier between the pus and the brain tissue. At *b* in Figure 64 there is an area of hemorrhagic extravasation, the result of thrombosis, which is also well shown in Figure 65, the destructive process entirely replacing the usual proliferative reaction. The merely necrotic end-result of the destructive process is shown in Figure 66.

Abscesses of this type also occur as secondary lesions to firm wall abscesses. In Figure 67 the primary abscess has a thick wall, the building of which, no doubt, required several weeks, but the extension from this abscess was doubtless more recent, due to escape of pus into the substance of the

FIG. 65.—Section from *c* in Figure 64. Note the large and small areas of thrombosis. ×85

occipital lobe, an invasion altogether too sudden to allow the slowly proliferating glial tissue to form a protecting membrane.

D. F., age 29. Gunshot wound left hemisphere, July 14, 1918. Constant drainage of pus from the wound. Drainage of abscess, June 22, 1919. Death, June 30.

The architecture of the wall of the primary abscess is similar to that described under Group II. The firmness of the wall and heavy consistency of its content indicate a long duration. At *b*, however, is a larger abscess cavity with soft necrotic walls evidently due to a more recent extension from the original abscess.

Figure 68 shows an abscess, also the result of extension from the firm-wall abscess, as seen in Figure 55. There was evidently leakage of pus into the occipital pole of the ventricle which was shut off anteriorly from the remaining part of the ventricle so that the occipital pole was converted into an abscess cavity. Extending from the ventricle to the inferior surface of the brain, an

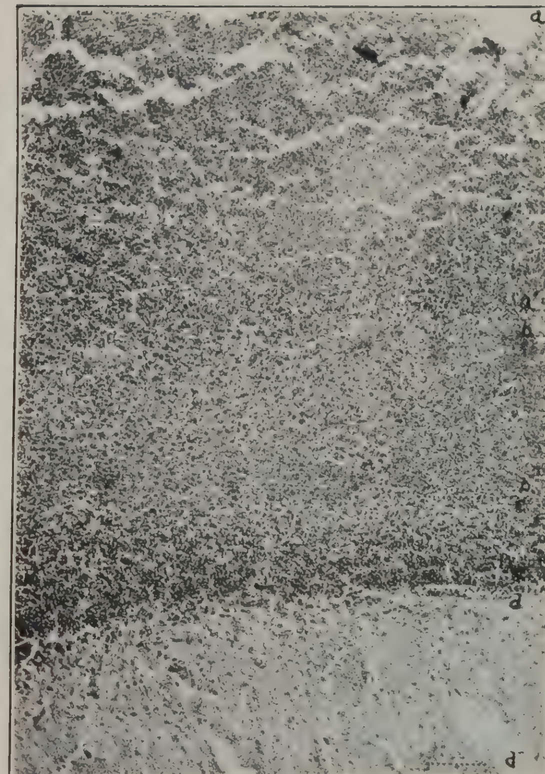

FIG. 66.—Section from d in Figure 64. a to a', Necrotic tissue surrounding the abscess cavity; b to b', nervous tissue beyond the area of necrosis; c to c', layer of granular cells of the cerebellum; d to d', molecular layer of the cerebellum. ×85

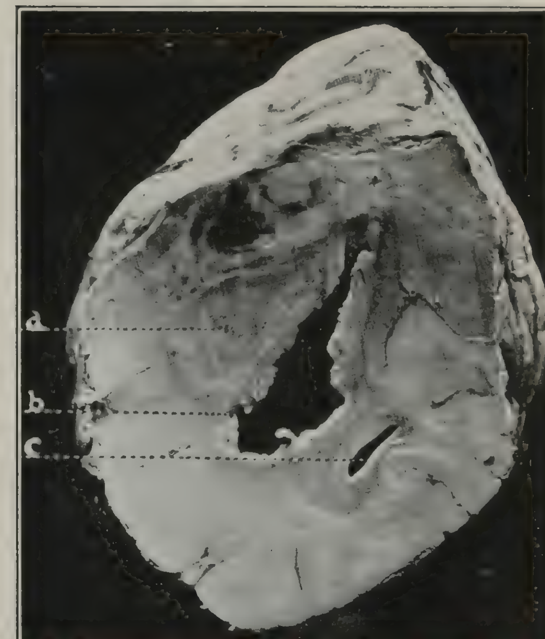

FIG. 67.—D. F. A transverse section through occipital pole of brain. a, Primary abscess with firm wall; b, secondary abscess cavity; c, occipital pole of lateral ventricle

FIG. 68.—P. V. Transverse section through the occipital pole of the brain shown in Figure 55. *a*, Occipital pole of the lateral ventricle converted into abscess cavity with necrotic wall; *b*, area of encephalitis, tract of evacuation of pus from the ventricle cavity to the subarachnoid space; *c*, thickened pia-arachnoid; *d*, site of section shown in Figure 69

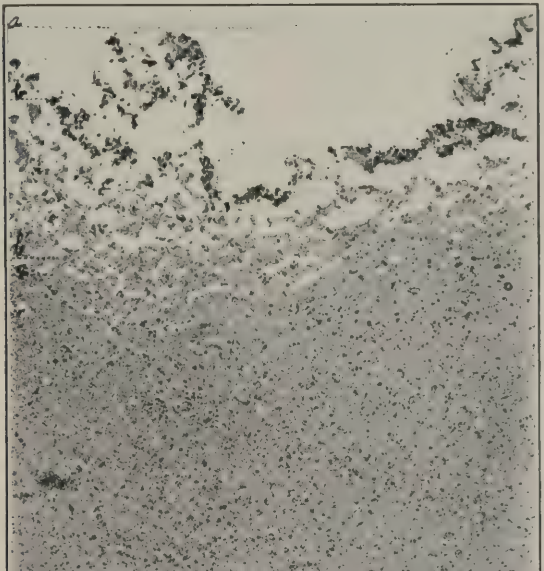

FIG. 69.—P. V. Section of the abscess wall at *d* in Figure 68. *a*, Abscess cavity; *b* to *b′*, necrotic brain tissue surrounding pus; *c* to *c′*, brain tissue beyond the necrotic zone. ×85

inflammatory tract marks the site of the escape of pus into the subarachnoid space.

Figure 69 is a section from the ventricle wall of the specimen shown in Figure 68, illustrating the poor quality of the abscess wall, which consists only of necrotic brain tissue entirely incapable of acting as a barrier to the pus content in the cavity.

The escape of pus from the abscess into the ventricle is a very common method of termination of neglected abscesses, but the conversion of a portion of the ventricle into an abscess cavity as shown in Figure 66 is certainly an uncommon reaction. The formation of secondary abscesses may be due to the ineffectiveness of an abscess wall as a barrier to constantly accumulating pus, or to organisms, so that such extension is dependent upon the duration of the abscess and the virulence of the organism producing it.

The following case reported by Frazier [1] illustrates the difficulties in the management of a tubular abscess of the left frontal and parietal regions, resulting from a penetrating gunshot wound, with retained bone fragments and metallic foreign bodies.

Private M, admitted to U. S. Army General Hospital No. 11, November 10, 1918, as an ambulatory case. He was unable to give history of his disability. He received a gunshot wound of the right frontal region near the midline, date unknown. There was a circular cranial defect in the right frontal region about 2 by 2½ cm., without hernia. The Roentgen-ray examination showed several bone fragments near the defect and a foreign body 0.5 by 4 cm. in the parietal cortex above and behind the left ear. There were no definite motor, sensory, or other focal symptoms present. He appeared to understand what he heard but refused to speak at first. About two weeks after admission he spoke more freely. The sudden development of a hernia at the site of the frontal defect, accompanied with other signs of compression was the indication for an exploratory operation. The site of the hernia in the frontal region was explored for abscess, with negative results. The patient subsequently died. The autopsy revealed a chronic meningitis and an abscess cavity along the tract of the missile. Death was attributed to chronic meningitis and hydrocephalus rather than to the abscess.

REPORT OF NECROPSY

Dura.—There was an oval opening to the right of the midline in the frontal portion, through which the brain herniated. Beneath the dura, covering the anterior part of the left hemisphere, there was evidence of a hemorrhagic pachymeningitis.

Hernia.—Beginning at a point 3.5 cm. above the base of the brain, anteriorly and just to the right of the midline, there was an irregularly rounded mass measuring x by 3.5 cm. beyond the frontal lobe.

Ventricles.—Both ventricles were dilated. The right showed 11.5 by 6.4 cm. in its greatest dimensions. At one point the left wall of the right ventricle projected 1.4 cm. to the left of the midline. The ependyma showed irregular areas of grayish white thickening. The choroid plexus of the posterior was thickened and firmly attached to the right lateral wall. The left lateral ventricle appeared to be less dilated than the right.

Abscess cavity.—Beginning just to the left of the falx and extending outward and backward to the surface in the anterior central gyrus there was a pale orange-yellow granular zone measuring 6 cm. in length, 1.2 to 2.5 cm. in width and 3.9 cm. in diameter. The central portion of this zone was occupied by a cavity filled with gelatinous and gray amorphous material.

The autopsy findings in this case show no rupture of the abscess and no acute meningitis. The general ventricular dilation indicates a chronic infection of the ventricles with possible obstruction of their exits. It should be

noted that the abscess cavity did not extend to the metal foreign body but probably originated from the bone fragments near the defect.

The intracranial pressure in the case was probably due to chronic inflammatory obstruction of the exits from the ventricles. This pressure, however, was offset to some extent, after the abscess began to form, by the cranial defect in the frontal region. Effective drainage of such an abscess would have been accomplished with great difficulty.

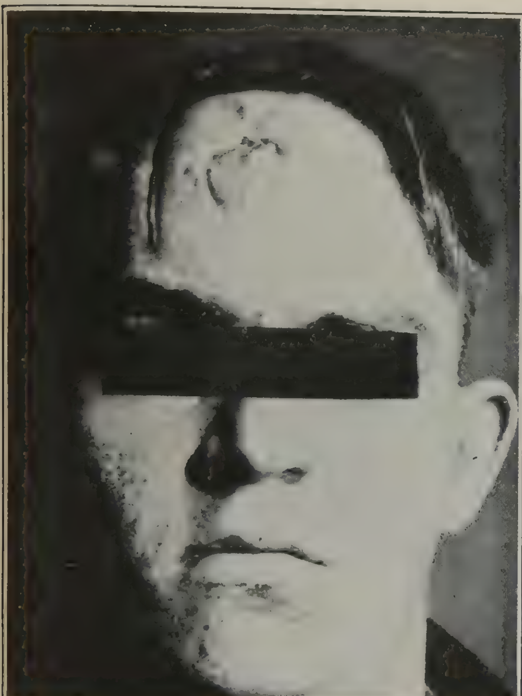

FIG. 70.—Patient with hernia at the site of the frontal defect. NOTE.—This photograph refers to autopsy specimen (fig. 71)

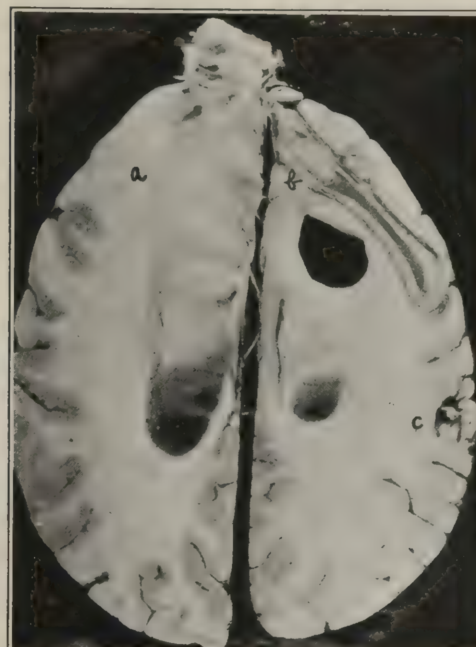

FIG. 71.—Brain showing (*a*) enlargement of left hemisphere and hernia cerebri at site of cerebral defect; (*b*) horn of dilated ventricle in relation with tubular abscess cavity filled with inspissated pus; (*c*) bullet just beneath the cortex. Note relation of abscess cavity to trajectory between site of hernia and location of bullet

Figure 72 shows an abscess following a penetrating gunshot wound in which the bullet entered the skull near the coronal suture of the left side and passed backward through the motor area, lodging in the cortex of the left occipital lobe. The wound was received three months before an operation was undertaken for the removal of the bullet. The patient was recovering from aphasia and a right motor paralysis, but there was a residual hemianopsia. At the operation, which was done under local anesthesia, the bullet was found embedded in the cortex and was definitely encapsulated by a small cyst, which lay in an angle between the longitudinal and left lateral sinus. A cerebral abscess was not searched for, there being no symptoms suggesting a progressive intracranial distrubance. The bullet was removed without difficulty and a rub-

ber tissue drain inserted into the small cyst cavity. The culture of the bullet proved negative, but 12 hours later the patient showed signs of meningitis and died within 36 hours. Streptococci were grown from the spinal fluid.

In this case hemianopsia caused by the original injury combined with a residual disturbance of speech function and intelligence, due to a destructive lesion, had masked any possible signs of focal disturbance arising from the abscess itself. An exploration which approached within 1 cm. of the abscess wall led to no information that an abscess was present. In the manipulation necessary to remove the bullet either a latent infection about the abscess wall was brought into activity or else the wall was weakened and rupture took

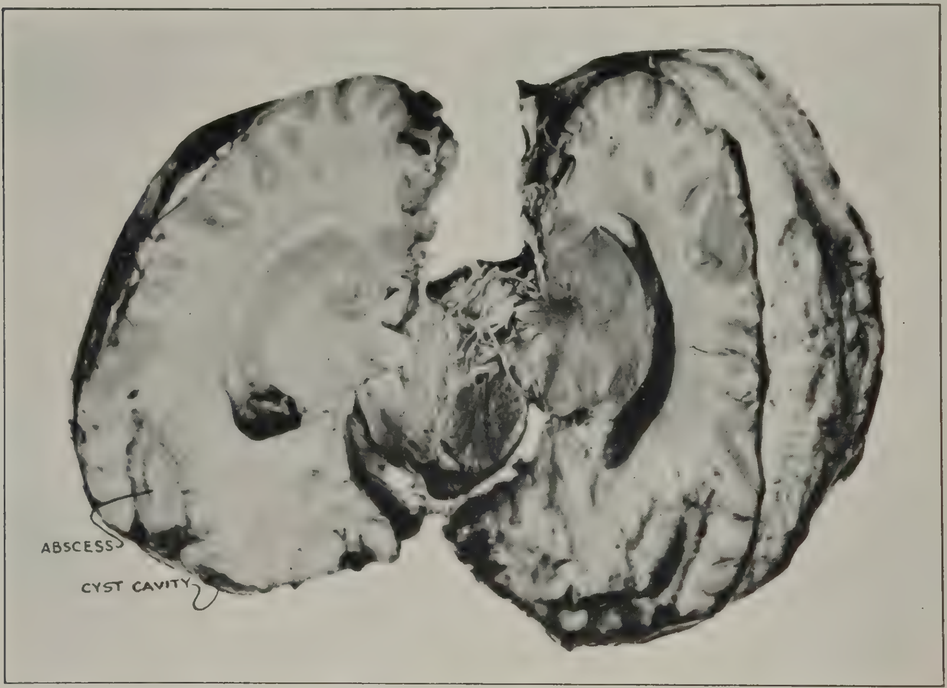

FIG. 72.—Abscess from penetrating gunshot wound of left parietal and occipital lobes. There were no retained bone fragments. Note collapsed cyst cavity from which sterile bullet was removed. This is well separated from abscess, which was not discovered at operation

place. The case further illustrates the possibility of removing a sterile missile which in its course had deposited infection which led to an abscess some distance from the projectile.

The symptoms of brain abscess in which there is a cranial defect or a discharging sinus may not include such marked evidence of intracranial pressure as is frequently seen in cases with abscess following infection from the accessory sinuses. If there is a cranial defect the tension is offset to some extent by protrusion of the tissues through the bony opening, much in the same way as subtemporal decompression offsets intracranial pressure from other causes. In some cases the discharging sinus from a foreign body which has become the seat of an abscess may delay or prevent the accumulation of pus whereas in

others the escape of pus through the sinus is inadequate to prevent the formation of an abscess of considerable size. The presence of a retained foreign body associated with a progression of symptoms or the accession of new symptoms indicating cerebral impairment should obviously arouse the suspicion of abscess formation.

As was mentioned at the beginning of the consideration of this subject, the mortality of brain abscess from war wounds is very high. Bagley,[6] in his pathological study of abscesses, referred to above, reports four cases following war wounds of the head. Two of the patients recovered and two died. In one case which recovered there were no symptoms of neurological disturbance and the operation was undertaken for the removal of a machine-gun bullet from the right cerebellar hemisphere. Abscess was unexpectedly encountered. In a second case with recovery, the wound of entrance continued to drain until a temporal lobe abscess was evacuated. This patient also had metallic foreign body in the middle cranial fossa. Both of the fatal cases had retained bone fragments and in both of these cases the wound remained unhealed.

A number of factors must be taken into consideration in attempting to give a fair estimate of the mortality of the operation in brain abscess. The type and stage of infection, presence or absence of capsule, location of the abscess, and the method of drainage has each a direct influence upon the operative mortality. In view of the high mortality any method of operation should be carefully scrutinized to exclude all technical errors, which may not only prevent the eradication of a localized suppuration but may actually spread the infection to uninvolved regions of the brain. The principles utilized in the successful treatment of abscess in other regions of the body must be modified in operations for brain abscess.

The best results in the treatment of brain abscess have been obtained in the drainage of single abscesses with capsules. Multiple abscesses are practically always fatal and recovery from brain abscess without a capsule is extremely rare. If an encapsulated abscess is connected with the meninges by adhesions and the evacuation of the pus is properly conducted through the adherent cortex, the mortality rate of cerebral abscess in general should be very much reduced.

Much has been written about the importance of early diagnosis and drainage of brain abscess. The primary stage of abscess formation is one of septic encephalitis for which surgical procedures will give no relief. To recognize the stage of encephalitis is highly desirable but it is equally as important to have in mind the limitations of surgery at this period in the evolution of infection. The ideal time of operation is after the formation of the capsule and it has not been shown that deferred operations for abscess, provided rupture has not taken place, has appreciably raised the mortality rate. It is sometimes difficult to determine just how drainage of pus should be accomplished or whether simple aspiration with a needle should be made. It is highly probable that in many fatal cases the drainage tube does not enter the abscess cavity but lies in the brain tissue about the abscess, traumatizing the brain and producing a septic encephalitis.

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In deep-seated small abscesses it is almost impossible to reenter the abscess cavity with a drainage tube after the withdrawal of the instrument used for exploration. For this reason exploration should be done with some form of instrument which may be left in position when a deep subcortical abscess is entered. Graduated drainage of abscesses has been advocated to prevent contamination of the meningeal spaces.[8] By this method the abscess is first located and the distance from the cortex carefully measured. A small amount of pus is aspirated to relieve tension and a narrow strip of rubber tissue placed down to but not into the abscess. A few days later the eye end of a soft catheter is inserted through the opening made for the rubber tissue.

The advocates of this method believe that meningitis is less likely to result because of the formation of adhesions about the opening in the dura before free drainage is instituted. Such a procedure would be unnecessary in gunshot wounds if the abscess can be reached through the original defect where adhesions of the cortex to the tissues of the scalp have already formed. It is not known whether septic encephalitis, due to fumbling with the primary drainage or meningitis from overflow of pus on to the cortex, is the most frequent cause of death after the operation. If the intracranial pressure is high before the abscess is drained it is not likely that the cortex will recede from the dura during the evacuation of the pus. Moreover, it is difficult to control the escape of pus from abscesses with high tension situated within one centimeter of the cortex. A consideration of all the facts justifies the conclusion that the most favorable time for accurately placing a drainage tube in an abscess cavity is when the pus is first discovered. It is often possible to empty the abscess completely at this time and there may be very little subsequent discharge. If metallic foreign bodies or bone fragments are in the abscess cavity or about the capsule every effort should be made to remove them. If, however, the abscess has developed some distance from a retained foreign body, inspection of the abscess cavity is probably unnecessary and adds to the risks of the operation. In cases of large cerebral abscess the expansion of the abscess has been at the expense of the space normally occupied by the lateral ventricle. Liberation of the pus is followed by reaccumulation of fluid in the ventricle which has been compressed by the abscess and this expansion of the ventricle after the evacuation of the pus serves to maintain the contact of the cortex with the dura.

Procedures for the drainage of abscesses vary in magnitude, all the way from the osteoplastic flap to a simple trephine opening. Bone flap operations are of considerable magnitude in very ill patients and appear to be justified only on the ground that often the operation is exploratory in character and that the exposure of a wide area of cortex gives a better opportunity for searching for a collection of pus which might be overlooked when a small opening is used. As far as the treatment of subcortical abscess is concerned, the bone flap offers no advantages. The advocates of both the simple exploration through a small perforation and the osteopathic flap finally drain a subcortical abscess through a short dural incision so that the extensive procedure of raising the flap is entirely unnecessary in the actual evacuation of this type of abscess. One great advantage of the drainage of an abscess through a small

cranial opening is that the method is simple and can be employed without the use of general anesthesia. Troublesome osteomyelitis of the skull as a late complication is also avoided by this method.

The importance of utilizing the force of gravity in evacuation of brain abscess is generally recognized. The satisfactory results of operation of encapsulated temporal lobe abscess when the abscess cavity is entered at its lowest level illustrates this point. On the other hand, the evacuation of the deep frontal abscess through the vertex is usually accompanied by considerable interference with drainage. In some cases there is very little drainage after primary evacuation, in others drainage continues for many weeks and there may be during this period temporary cessation of the discharge accompanied by an increase of existing symptoms, or an accession of new symptoms.

The drainage tube should be carefully fixed to the scalp and should not be removed until drainage is discontinued. In some cases, particularly those in which the evacuation is primarily complete, the tubes may be extruded in 10 days or 2 weeks. Healing may then proceed rapidly and the patient is entirely relieved of the symptoms. In other cases the tube can not be kept in satisfactorily even from the beginning and the patient shows signs of an extension of the infection. It is likely that most of these latter patients have a spreading encephalitis about the abscess and the increase of intracranial pressure forces the tube out of the cranial cavity. The question of just how long drainage should be continued is difficult to answer. Some have recommended that the tube be kept in position for several months. In this connection it must be borne in mind that there will be some drainage from the reparative efforts of the tissues as long as the tube is kept in position. Such being the case, if the patient appears to be doing well and the drainage is scanty, it would seem safe to begin the shortening of the tube after two or three weeks and remove about one-eighth of an inch of the tube every second day until it is finally withdrawn.

FUNGUS CEREBRI

One of the most frequent complications of the drainage of brain abscess is a fungus of the brain; however, this complication was rarely present among head injury patients returned from overseas. The mortality of the condition which produces fungus is high. An uncovered protrusion commonly develops after compound fracture of the skull with laceration and infection of brain tissues. The principle of complete removal of débris with excision of contaminated tissues and tight closure of the wound at the primary operation not only prevents fatal early infection but serves to eliminate the formation of cerebral fungus. The condition responsible for fungus following brain injury is an expanding lesion due to infection. The pathology of this lesion may be undrained abscess, with or without obstructive hydrocephalus (fig. 73). A more frequent cause is probably encephalitis (fig. 74). The complication of brain abscess by fungus, even when a fatal result is avoided, greatly prolongs the patient's convalescence and adds generally to the postoperative difficulties. The treatment of the condition itself is, as a rule, unsatisfactory. It is important to drain any accumulation of pus, if this is

FIG. 73.—Fungus following a subtempora :exploration for multiple right frontal abscesses. Two abscesses were evacuated through a small perforation in the frontal bone, which shows a small fungus in the photograph. One abscess was overlooked. Autopsy showed widespread encephalitis

possible, but the recognition of the refilling of part of the abscess cavity or the diagnosis of new abscess in or about the fungus is beset with many difficulties. The exploration of the fungus with a ventricular needle may carry infection into the ventricle, the horn of which may extend well into the protrusion. If the cause of the fungus can not be located and removed the exposed portion of the brain should be protected by rubber tissue and a firm ring of gauze. The pad should be sufficiently thick to protect the fungus from further injury by the bandage. If the intracranial pressure is raised, and fungus does not often exist unless it is, daily spinal punctures are helpful. The patient should spend a part of each day sitting up in bed if the fungus is near the vertex, so as to reduce the intracranial pressure about the protrusion. A subtemporal decompression may sometimes be of benefit in the treatment of fungus, but it is of no value if there is an obstructive hydrocephalus. The complete eradication of infection through a small dural incision is the best protection against the development of fungus following abscess. If the abscess cavity is not well drained an extrusion of brain tissue of considerable size may take place through a very short dural incision and a fungus developed under such conditions tends to increase in size from mechanical interference with the blood supply of the extruded brain.

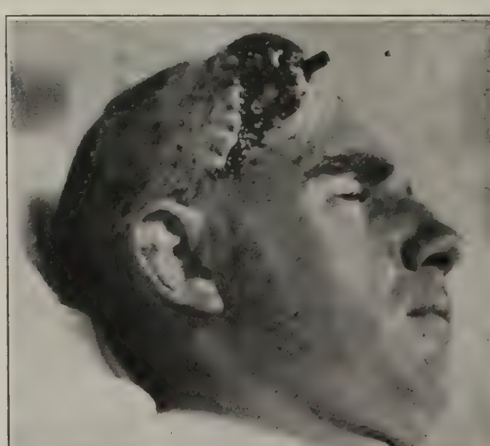

FIG. 74.—Fungus complicating the drainage of a large abscess of the right frontal lobe. Incomplete early drainage with encephalitis was probably responsible for the fungus. Complete recovery followed the protection of the fungus by a doughnut pad, and spinal punctures

RETAINED FOREIGN BODIES

The relatively small number of retained foreign bodies discovered in head-injury patients following their return to the United States is striking proof of the efficiency which characterized primary operation for penetrating wounds of the brain. In two series aggregating 392 head-injury patients, at General Hospitals Nos. 2 and 11, 29 had intracranial foreign bodies which were either pieces of metal or bone fragments. It is not unusual to find small metallic bodies associated with bone fragments in the same patient.

A foreign body, even of considerable size, rarely produces symptoms unless infection develops either in the tract of the missile or about the foreign body itself. It is not rare for foreign bodies to remain quiescent in the brain for a year or more and then become the seat of an abscess. There is usually a limited zone of sclerosis of the tissues about the foreign body, but it is doubtful if this often results in progressive impairment.

In view of the fact that a foreign body often deposits infection in the brain and that this infection may be present even when the clinical condition of the patient indicates that the foreign body is quiescent, the question of extraction of the foreign body should always receive consideration. If the abscess which forms in cases with retained foreign body always develops in the location of the foreign body, the argument is much stronger for its removal either to prevent infection or to eradicate a latent infection. It often happens, however, that an unsuspected abscess may lie some distance from the foreign body the removal of which does not affect the abscess itself. In some cases the missile projects into or is inclosed by the abscess wall as in the following case reported by Bagley:[4]

Pvt. P. L.—Right occipital penetration by machine-gun bullet which lodged in the right cerebellar hemisphere; extraction of bullet and drainage of abscess; recovery. The patient was wounded September 27, 1918, and admitted to a front line hospital in good condition. There was no attempt made at that time to remove the bullet. When brought under observation at General Hospital No. 2, Fort McHenry, Md., in April, 1919, the Rœntgen-ray findings were the only clinical evidence of the presence of the bullet. Removal of the missile was advised because of its large size and the fact that the procedure seemed to offer no difficulties.

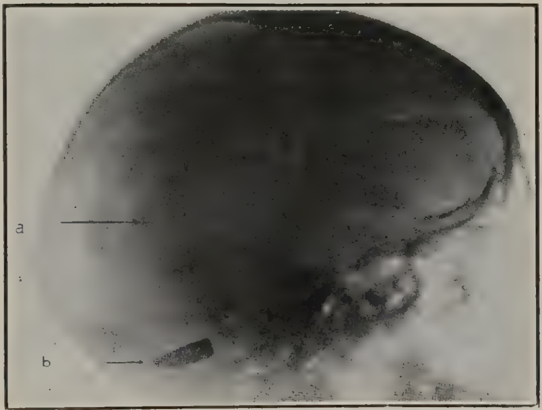

FIG. 75.—Case 1: *a*, Point of entrance; *b*, machine-gun bullet in right cerebellar hemisphere

Operation, May 19, 1919. A unilateral cerebellar exposure was made. After deflecting the right flap a small portion of bone was removed and a transverse incision made in the dura. There were a few delicate adhesions between the dura and the pia-arachnoid. An exploring needle passed 0.5 cm. into the hemisphere encountered the bullet. Division of the cortex resulted in a free flow of pus. Further examination revealed a small abscess cavity in the right cerebellar hemisphere which contained about 3 cubic centimeters of pus. Into the

abscess cavity the distal two-thirds of the bullet projected while the approximate one-third was firmly encapsulated in the right wall of the abscess. The bullet was removed and immediately placed in culture media, examination of which later showed a growth of staphylococci. Folded rubber tissue drains were placed in the abscess cavity and brought to the surface at the outer extremity of the transverse incision. Forty-eight hours after operation there was

Fig. 76.—A "shower" of metallic fragments partly intracerebral and partly extracerebral

some headache and elevation of temperature. Drainage continued until November 1, 1919 when there was complete healing. At no time during this period was there evidence of disturbance of the cerebellum.

In a series of nine patients with retained missiles treated by Bagley, seven were operated upon. Of the operated cases, four had an abscess, with

a positive culture. In three cases there appeared to be no signs of brain disturbance from the foreign bodies, and in these the cultures were negative. In the patients who showed no infection from the missile there was prompt recovery, and they are perhaps free from the menace of infection in the future.

It is generally recognized that bone fragments or organic débris are more likely to produce late abscess formation than a metallic foreign body, and in some cases with retained metal and bone fragments the metal had passed well beyond the location of the abscess about the bone fragments and appeared to be giving no trouble.

Fig. 77.—Large single metallic fragment, intrahemispheric

Frazier [1] is of the opinion that the indications for the extraction of foreign bodies are as follows: Foreign bodies causing encephalitis or epileptic seizures should be extracted; those apparently latent should be left alone.

The following case, reported by Frazier and Ingham, was operated upon because of Jacksonian epilepsy, which was correlated with the region of the brain having a retained missile.

The patient, who was struck by a high-explosive shell in the frontal region just above the eyebrow, received first aid at once. He was operated on at the field hospital. Fragments of bone were removed and the wound closed with tube drainage. September 27, 1918, the wound

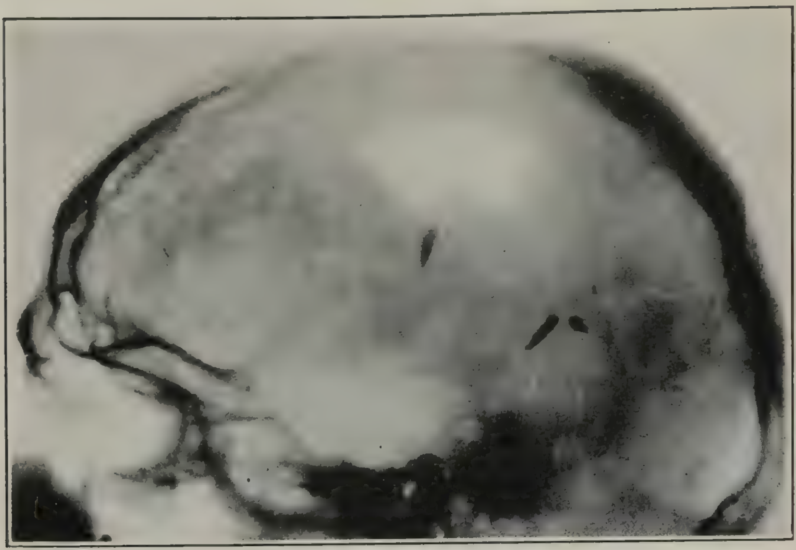

FIG. 78.—Three metallic fragments at a distance from the defect; two bone fragments within the margin of the defect

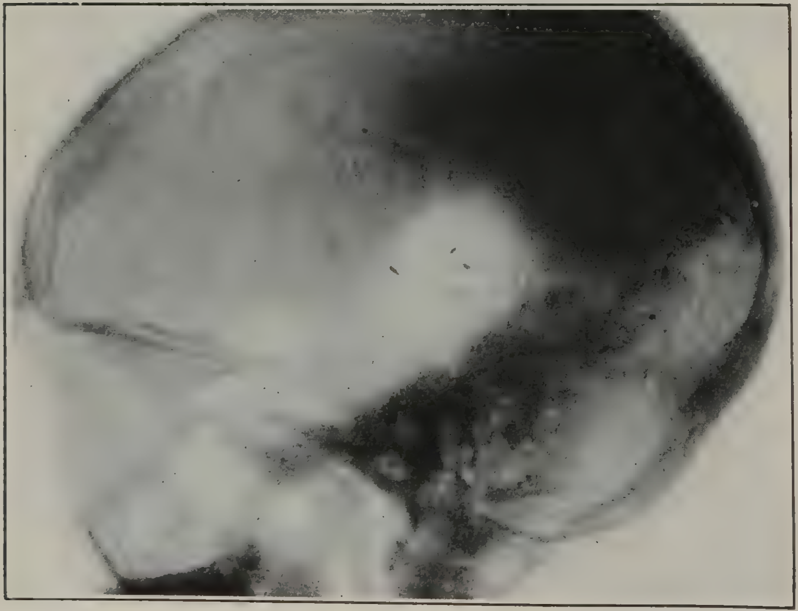

FIG. 79.—One minute bone fragment and three silver clips applied at operation overseas for control of hemorrhage

had healed. He was operated on June 9, 1919, at General Hospital No. 11. Craniotomy was performed for removal of a foreign body which was localized by measurements and identified by its relation to the bifurcation of the anterior middle meningeal artery, grooves of which could be seen in the skiagraph. The foreign body was located with a needle and extracted with a magnet. It appeared to be covered with soil. The sinus from which it was extracted was dinsinfected with dichloramin-T and the wound closed. Just before leaving the operating table the patient had a short convulsive seizure involving the left face, left arm, and left leg.

The foreign body was readily localized and its close proximity to the precentral convolution justified the belief that it might have been the exciting factor in the epileptic seizures. At all events this possible relationship, the fact that there had been but two seizures, that the foreign body could be removed without risk to life or harmful damage to the brain, justified its removal.

While it is difficult to give definite rules for the extraction of apparently quiescent foreign bodies in the brain, it may be said that all easily accessible foreign bodies, except minute fragments, should be removed. Foreign bodies deeply embedded in the brain without giving symptoms, should be left alone. A precise Roentgen-ray localization is necessary before operation. After the localization has been made, a small incision through the brain tissues and the removal with alligator forceps is perhaps the most satisfactory method of extracting the foreign body. An osteoplastic flap is rarely necessary, and the operation may be done under local anesthesia. The magnet extraction of foreign bodies after healing is complete is less easily carried out than at the primary operation. The fibrous tissue encapsulation and the entanglement of the missile in the scar make removal by a magnet difficult and increase the trauma of the brain tissues.

Bagley's[4] suggestion that a rubber tissue drain be kept in the cavity from which the foreign body is removed until the culture proves negative is important.

Generally the presence of a foreign body is considered a contraindication to cranioplasty and patients would often urge the removal of them so that a cranial defect could be repaired.

EPILEPSY

Convulsions were of frequent occurrence following gunshot wounds of the head, quite commonly appearing after the primary operation and often upon evacuation of the patient to another hospital. The early attacks were sometimes Jacksonian in type, but patients who had these early convulsions did not appear to be more liable to the development of epilepsy later on.

There is a great variance in the statistics as to the incidence of epileptic seizures following head wounds. In the series of 200 head cases at General Hospital No. 11 there were 25 patients with convulsions, or 12.5 per cent, while Villandre [9] reported operations on 70 per cent of a series of 450 cranial wounds in which the main indication was the development of epileptic seizures.

The type and location of the wound appear to be factors in the production of epilepsy. Patients with infected wounds and dense scars, particularly those of the motor cortex, seem to be more liable to late convulsions, but no head wounds are exempt from this complication.

In view of the many procedures which had been proposed for the relief of epilepsy it is surprising that surgery for the relief of this condition received

no accessions from the management of patients during the late treatment period. Some patients with cranial defects of the parietal region which were covered by dense scar appeared to be benefited by cranioplasty and there was rather general support of the operation for the repair of defects in such cases.

It is difficult to make deductions as to the effects of cranioplasty upon epilepsy in patients with large cranial defects. It is certainly true that many of them were relieved of a train of discomforts and that the convulsions appeared to be less frequent after the excision of dense scars and a repair of the defect.

Retained foreign bodies in the motor area of patients with Jacksonian attacks furnish a clear indication for operation and the removal of the foreign body.

Apart from the relatively few cases in which there were troublesome cranial defects or intracranial foreign bodies, surgical procedures were rarely used in the treatment of traumatic epilepsy.

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CHAPTER VI

A STATISTICAL ANALYSIS OF GUNSHOT WOUNDS OF THE HEAD

General statistics concerning gunshot wounds of the head are included in the tables on the various kinds of battle injuries sustained by members of the American Expeditionary Forces, in Chapter III of Section I of this volume. The data referred to show that of the 174,296 battle injuries, 10,452 were gunshot wounds of the head, a percentage of 5.99. Eleven hundred and forty-six of these head injuries (10.89 per cent) resulted fatally.

For purposes of a more detailed statistical study of these gunshot wounds of the head, about 1,100 clinical records, pertaining to such injuries, were selected and studied. Tabulations were made therefrom according to the regions involved, the symptoms presented, the operations, complications, persistent symptoms, dispositions, and causes of death. At this point it might be well to add that some of the clinical histories were remarkably complete and accurate; others were lacking in detail. However, considering the adverse conditions under which the original entries often were made, the preponderance of good case records is surprising. The material thus made available, representing approximately one-tenth of the whole, and being about 75 per cent adequate for the purpose, gives a fairly accurate cross section of all the cases.

In the analysis of these clinical records the grouping of Cushing is used. Since this grouping is given in detail in other chapters of this volume no further explanation of it is deemed advisable here.

CLASSIFICATION OF WOUNDS

Table 1 records the cases as to regions of the head involved according to the depth of the injury or severity. It will be noted that bursting fractures of the skull, listed in Class IX are relatively rare, the number of cases recorded being too small to be of value. Penetration of the ventricular system was also only occasionally noted. The largest total is in the frontal region, the smallest in the suboccipital. Probably the great majority of such injuries succumbed before admission to a field or evacuation hospital. When admitted alive and dying shortly after, they were probably recorded as fractures of the skull without further qualification. Therefore the largest group is that of Class II, simple fracture of the skull.

TABLE 1.—*Classification of gunshot wounds of the head, according to depth of injury, or its severity* [a]

ABSOLUTE NUMBERS

Regions	Classification									
	I	II	III	IV	V	VI	VII	VIII	IX	Total
Eye	4	6			2		46			58
Frontal	31	99	33	35	25	1	68	6	3	301
Temporal	33	63	21	22	15	1	28	6	3	192
Parietal	58	93	42	50	24	2	3	7		279
Vertex	3	10	2	4	2			1	1	23
Occipital	48	51	15	25	21	2	3	4	3	172
Suboccipital	1	1	1	1	1				1	6
Mastoid	21	30	3	3	4		15		1	77
Total	199	353	117	140	94	6	163	24	12	1,108

PERCENTAGES

Regions	I	II	III	IV	V	VI	VII	VIII	IX	Total
Eye	2.01	1.70			2.13		28.22			5.24
Frontal	15.57	28.05	28.21	24.99	26.59	16.67	41.72	25.00	25.00	27.17
Temporal	16.59	17.85	17.95	15.72	15.95	16.67	17.17	25.00	25.00	17.33
Parietal	29.14	26.35	35.90	35.71	25.53	33.33	1.84	29.17		25.18
Vertex	1.51	2.83	1.71	2.86	2.13			4.17	8.33	2.08
Occipital	24.12	14.45	12.81	17.86	22.34	33.33	1.84	16.67	25.00	15.52
Suboccipital	.50	.28	.85	.71	1.06				8.33	.54
Mastoid	10.55	8.50	2.56	2.14	4.26		9.20		8.33	6.95
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[a] Source of information, sick and wounded reports made to the Surgeon General.

SYMPTOMS

In Table 2 are the symptoms presented by the cases. The discrepancies are many—no doubt from lack of opportunity carefully to examine and record the findings. This is evidenced by the preponderance of records of outstanding symptoms such as blindness (85 cases) over such symptoms as amnesia, which was certainly more common than these records show (18 cases). Thus there are eight cases of extraocular paralysis recorded, but only two of diplopia. Again it is surprising to find that there were only 13 cases with hemianopsia, while we see in Table I 99 cases of occipital injury with definite cerebral injury.

Table 2.—*Symptoms* [b]

Symptoms	I	II	III	IV	V	VI	VII	VIII	IX	Total
ABSOLUTE NUMBERS										
Unconsciousness	4	26	13	20	15	2	4	4		88
Received dead									1	1
Paralysis	4	41	24	38	14	1	3	1	1	127
Hemiplegia	1	17	14	24	9	1	2			68
Paraplegia	1	3	4	3				1		12
Monoplegia	2	21	6	11	5		1		1	47
Cranial nerve palsies	7	25	15	12	3		27	3		92
Olfactory	1			1						2
Optic		1	2	1			1	1		6
Ocular motor		1		1						2
Trochlear		2					1			3
Trigeminal		3	2	1			3			9
Abducens		1	2							3
Facial	5	13	8	7	3		18	1		55
Auditory	1	3	1				3			8
Glosso-pharyngeal		1								1
Vagus										
Spinal accessory							1			1
Hypoglossal				1				1		2
Sight	5	12		11	11		59	3		101
Blindness	4	9		6	5		58	3		85
Hemianopsia	1	1		4	6		1			13
Diplopia		2								2
Strabismus				1						1
Hearing	8	22	14	11	4		18	2		79
Partial	6	8	5	4	1		6	1		31
Deafness	2	14	9	7	3		12	1		48
Cerebral symptoms	6	14	13	23	18		2	4	1	81
Aphasia	2	7	4	12	7			2	1	35
Amnesia	3	1	2	6	5		1			18
Apraxia				1			1			2
Agraphia		1								1
Epilepsy	1	5		4	2			1		13
Convulsions			1		1					2
Delirium			6		3			1		10
PERCENTAGES										
Unconsciousness	2.23	8.78	13.40	17.54	18.75	50.00	3.88	26.67		9.72
Received dead									5.88	.11
Paralysis	2.24	13.84	24.74	33.62	17.50	25.00	2.91	6.67	5.88	14.04
Hemiplegia	.56	5.74	14.43	21.04	11.25	25.00	1.94			7.52
Paraplegia	.56	1.01	4.12	2.63				6.67		1.33
Monoplegia	1.12	7.09	6.19	9.65	6.25		.97		5.88	5.19
Cranial nerve palsies	3.91	8.45	15.46	10.53	3.75		26.21	20.00		10.17
Olfactory	.56			.88						.22
Optic		.34	2.06	.88			.97	6.67		.66
Ocular motor		.34		.88						.22
Trochlear		.68					.97			.33
Trigeminal		1.01	2.06	.88			2.91			.99
Abducens		.34	2.06							.33
Facial	2.79	4.39	8.25	6.14	3.75		17.48	6.67		6.08
Auditory	.56	1.01	1.03				2.91			.88
Glosso-pharyngeal		.34								.11
Vagus										
Spinal accessory							.97			.11
Hypoglossal				.88				6.67		.22
Sight	2.79	4.05		9.65	13.75		57.28	20.00		11.16
Blindness	2.24	3.05		5.26	6.25		56.31	20.00		9.39
Hemianopsia	.56	.34		3.51	7.50		.97			1.43
Diplopia		.68								.22
Strabismus				.88						.11
Hearing	4.47	7.43	14.43	9.65	5.00		17.48	13.33		8.73
Partial	3.35	2.70	5.15	3.51	1.25		5.83	6.67		3.43
Deafness	1.12	4.74	9.27	6.14	3.75		11.65	6.67		5.30
Cerebral symptoms	3.35	4.73	13.40	20.18	22.50		1.94	26.67	5.88	8.95
Aphasia	1.12	2.37	4.12	10.53	8.75			13.33	5.88	3.87
Amnesia	1.68	.34	2.06	5.26	6.25		.97			1.99
Apraxia				.88			.97			.22
Agraphia		.34								.11
Epilepsy	.56	1.69		3.51	2.50			6.67		1.44
Convulsions			1.03		1.25					.22
Delirium			6.19		3.75			6.67		1.11

[b] Source of information, sick and wounded reports made to the Surgeon General.

PRIMARY OPERATIONS

Table 3 shows the primary operations performed. Since 1,056 are recorded, it is evident that many of those who were wounded had more than one primary operation. The zeal of the surgeon in noting what he did is in marked contrast to Table 2 of the symptoms his patients presented. It is interesting to note that 162 cases were treated by primary closure. In 195 the foreign body was removed at this time and only 33 were cleaned and dressed.

TABLE 3.—*Primary operations performed* [c]

ABSOLUTE NUMBERS

Primary operations	Classification I	II	III	IV	V	VI	VII	VIII	IX	Total
Decompression	3	59	26	11	9	3	4	4	2	121
Débridement	48	137	54	90	44	3	38	7	4	425
Removal of foreign body	25	68	25	21	28	2	22	3	1	195
Drainage	7	23	9	17	14		10	1	2	83
Closure	30	57	20	33	8	1	5	5	3	162
Enucleation of eye	1						33			34
Cleaned and dressed	14	10	2	1	2		2	1	1	33
Cranioplasty		2								2
Mastoidotomy		1								1

PERCENTAGES

Primary operations	I	II	III	IV	V	VI	VII	VIII	IX	Total
Decompression	1.68	19.93	26.81	9.65	11.25	75.00	3.88	26.67	11.76	13.37
Débridement	26.81	46.29	55.67	78.97	55.00	75.00	36.89	46.67	23.53	46.96
Removal of foreign body	13.97	22.97	25.77	18.42	35.00	50.00	21.36	20.00	5.88	21.55
Drainage	3.91	7.77	9.28	14.91	17.50		9.71	6.67	11.76	9.17
Closure	16.76	19.26	20.62	28.95	10.00	25.00	4.85	33.33	17.65	17.90
Enucleation of eye	.56						32.04			3.76
Cleaned and dressed	7.82	3.38	2.06	.88	2.50		1.94	6.67	5.88	3.65
Cranioplasty		.68								.22
Mastoidotomy		.34								.11

NOTE.—More than one primary operation was, of course, performed on many cases, hence the apparent discrepancy.
[c] Source of information, sick and wounded reports made to the Surgeon General.

SECONDARY OPERATIONS

Table 4 records the secondary operations performed. Bone fragments and foreign bodies had to be removed in 50 cases only, while drainage had to be established in only 32. Abscess occurred 15 times. This is an excellent indication of the thoroughness and success of the primary operations. In this table the record of 48 cranioplasties and 34 bone grafts shows the need of plastic repairs for cranial defects.

TABLE 4.—*Secondary operations performed* [d]

ABSOLUTE NUMBERS

Secondary operations	Classification									
	I	II	III	IV	V	VI	VII	VIII	IX	Total
Removal of brain tissue		3	1	2	2			1		9
Removal of bone fragment		7	9	10	8		1	1		36
Removal of foreign body	3	2	1	1	6		1			14
Drainage	2	7	7	5	8		3			32
Decompression		4		2	1					7
Excision of scar		8	1							9
Abscess		2	3	4	3		3			15
Cranioplasty	1	15	10	12	5		5			48
Closure, secondary		2								2
Mastoidectomy					1		1			2
Bone graft		11	9	11	2			1		34

PERCENTAGES

Secondary operations	I	II	III	IV	V	VI	VII	VIII	IX	Total
Removal of brain tissue		1.01	1.03	1.75	2.50			6.67		.99
Removal of bone fragment		2.37	9.28	8.77	10.00		.97	6.67		3.98
Removal of foreign body	1.68	.68	1.03	.88	7.55		.97			1.55
Drainage	1.12	2.37	7.22	4.39	10.00		2.91			3.54
Decompression		1.35		1.75	1.25					.77
Excision of scar		2.70	1.03							.99
Abscess		.68	3.09	3.51	3.75		2.91			1.66
Cranioplasty	.56	5.07	10.31	10.53	6.25		4.85			5.30
Closure, secondary	1.12									.22
Mastoidectomy					1.25		.97			.22
Bone graft		3.71	9.28	9.65	2.50			6.67		3.76

[d] Source of information, sick and wounded reports made to the Surgeon General.

COMPLICATIONS

In Table 5 the complications are recorded. The most frequent complication was hemorrhage, probably not of much moment in the great number of cases but dramatic when occurring and therefore more frequently noted. Infection of the wound was quite common (59) while meningitis and abscess were surprisingly infrequent. It is interesting to note that these records show only six cases of psychoneurosis.

TABLE 5.—*Complications of head injuries* [e]

ABSOLUTE NUMBERS

Complications	Classification									
	I	II	III	IV	V	VI	VII	VIII	IX	Total
Hemorrhage	4	15	18	11	4		5	1	3	61
Infection	8	16	4	12	9		9		1	59
Meningitis		2	6	7	9		4	1		29
Abscess		8	7	4	9		4		1	33
Hernia		4	6	18	3	1	3			35
Discharging sinus		6	5	9	4		1			25
Sinusitis	1						2			3
Psychoneurosis	3	1			1		1			6
Mastoiditis					1					1

PERCENTAGES

Complications	I	II	III	IV	V	VI	VII	VIII	IX	Total
Hemorrhage	2.23	5.07	18.56	9.65	5.00		4.85	6.67	17.65	6.74
Infection	4.47	5.41	4.12	10.53	11.25		8.74		5.88	6.52
Meningitis		.68	6.19	6.14	11.25		3.88	6.67		3.20
Abscess		2.70	7.22	3.51	11.25		3.88		5.88	3.65
Hernia		1.35	6.19	15.79	3.75	25.00	2.91			3.87
Discharging sinus		2.03	5.15	7.90	5.00		.97			2.76
Sinusitis	.56						1.94			.33
Psychoneurosis	1.68	.34			1.25		.97			.66
Mastoiditis					1.25					.11

[e] Source of information, sick and wounded reports made to the Surgeon General.

DISPOSITION OF CASES

The disposition of the cases of head injuries is shown in Table 6. Only 23 per cent died; 43 per cent were returned to duty; 26 per cent were judged to be unfit for further military duty; 5 per cent were sent to convalescent camps.

TABLE 6.—*Disposition of head injury cases* [f]

ABSOLUTE NUMBERS

Disposition	Classification									
	I	II	III	IV	V	VI	VII	VIII	IX	Total
Duty	131	175	22	21	11	3	28	2	1	394
S. C. D.	23	75	35	39	15		44	3	1	235
Died	6	30	31	50	46		22	8	14	207
Transferred to C. C.	13	12	6	3	8		7	1		50
Not stated	1				1				1	3
Remaining	3	3	2	1		1	1			11
Total	177	295	96	114	81	4	102	14	17	900

PERCENTAGES

Disposition	I	II	III	IV	V	VI	VII	VIII	IX	Total
Duty	74.02	59.33	22.92	18.42	13.58	75.00	27.45	14.29	5.88	43.78
S. C. D.	12.99	25.42	36.46	34.21	18.52		43.14	21.43	5.88	26.11
Died	3.39	10.17	32.29	43.86	56.79		21.57	57.14	82.35	23.00
Transferred to C. C.	7.34	4.07	6.25	2.63	9.88		6.86	7.14		5.56
Not stated	.57				1.23				5.88	.33
Remaining	1.69	1.02	2.08	.88		25.00	.98			1.22
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[f] Source of information, sick and wounded reports made to the Surgeon General.

PERSISTING SYMPTOMS

Table 7 shows the persisting symptoms. This table is interesting when compared with Table 2. Of 127 cases that presented some form of paralysis as a primary symptom, in only 66 did this paralysis persist, without considering the 23 per cent mortality that must have affected these figures. There are other discrepancies: Though 55 cases of facial palsy were recorded in Table 2, only 1 case of facial paralysis persisted or survived. Other cerebral symptoms were recorded as more careful studies were made, such as astereognosis and nystagmus.

TABLE 7.—*Persisting symptoms* [g]

ABSOLUTE NUMBERS

Symptoms persisting	Classification									
	I	II	III	IV	V	VI	VII	VIII	IX	Total
Paralysis	5	18	9	10	9		14		1	66
Deafness, complete or partial	2	22	7	11	6		14	2		64
Blindness	6	11	1	1	4		71	1		95
Partial	3	10	1	1	3		50	1		69
Complete	3	1			1		21			26
Aphasia	2	4	3	4	1					14
Ataxia					1					1
Amnesia	1		1	1	2		1			6
Apraxia					1		1			2
Epilepsy		4		3	2			1		10
Hemianopsia	1	1	1	5	4		1	1		14
Vertigo		2		1			1			4
Hemiplegia		5	3	1						9
Holmes-Sargent Syndrome			1							1
Slight nystagmus and right facial paralysis				1						1
Adiadokocinesis				2						2
Astereognosis				1	1					2
Cerebrospinal fistula								1		1

[g] Source of information, sick and wounded reports made to the Surgeon General.

TABLE 7.—*Persisting symptoms*—Continued

PERCENTAGES

Symptoms persisting	Classification									
	I	II	III	IV	V	VI	VII	VIII	IX	Total
Paralysis	2.79	6.08	9.28	8.77	11.25		13.59		5.88	7.29
Deafness, complete or partial	1.12	7.43	7.22	9.65	7.50		13.59	13.33		7.07
Blindness	3.35	3.71	1.03	.88	5.00		68.93	6.67		10.50
Partial	1.68	3.38	1.03	.88	3.75		48.54	6.67		7.62
Complete	1.68	.34			1.25		20.39			2.87
Aphasia	1.12	1.35	3.09	3.51	1.25					1.55
Ataxia					1.25					.11
Amnesia	.56		1.03	.88	2.50		.97			.66
Apraxia					1.25		.97			.22
Epilepsy		1.35		2.63	2.50			6.67		1.11
Hemianopsia	.56	.34	1.03	4.39	5.00		.97	6.67		1.55
Vertigo		.68		.88			.97			.44
Hemiplegia		1.69	3.09	.88						.99
Holmes-Sargent Syndrome			1.03							.11
Slight nystagmus and right facial paralysis				.88						.11
Adiadokocinesis				1.75						.22
Astereognosis				.88	1.25					.22
Cerebrospinal fistula								6.67		.11

CAUSES OF DEATH

Table 8 shows the causes of death as recorded. If "Not associated" and "Not stated" are disregarded, the preponderance of septic complications, accounting for 72 per cent of the deaths, is very striking. Of these meningitis was much the most common.

TABLE 8.—*Causes of death*[h]

ABSOLUTE NUMBERS

Causes of death	Classification									
	I	II	III	IV	V	VI	VII	VIII	IX	Total
Hemorrhage		3	2		1		1		2	9
Shock				4	2	1		1		8
Sepsis			1	2	1		2			6
Meningitis		2	6	7	10		7	1	2	35
Not associated	2	1		33	1		2			39
Not stated	4	23	18		24	1	10	6	6	92
Encephalitis			1							1
Abscess			2							2
Total	6	29	30	46	39	2	22	8	10	192

PERCENTAGES

Causes of death	I	II	III	IV	V	VI	VII	VIII	IX	Total
Hemorrhage		10.34	6.67		2.56		4.55		20.00	4.69
Shock				8.70	5.13	50.00		12.50		4.17
Sepsis			3.33	4.35	2.56		9.09			3.13
Meningitis		6.90	20.00	15.22	25.64		31.82	12.50	20.00	18.23
Not associated	33.33	3.45		71,74	2.56		9.09			20.31
Not stated	66.67	79.31	60.00		61.54	50.00	45.46	75.00	60.00	47.92
Encephalitis			3.33							.52
Abscess			6.67							1.04
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[h] Source of information, sick and wounded reports made to the Surgeon General.

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CHAPTER VII

EXPERIMENTAL STUDY OF PROBLEMS OF INFECTION OF THE CENTRAL NERVOUS SYSTEM AND THE TREATMENT THEREFOR [a]

During the existence of the Army Neurosurgical Laboratory the original plan of investigation was developed and extended. In some lines of activity progress was achieved, while in other phases no definite advances were made. The work of the laboratory is summarized in this chapter.

HYDROCEPHALUS [1]

One of the most frequent of the sequelæ of meningitis (particularly of the chronic type) is the development of an internal hydrocephalus. The experimental production of the condition was found to be possible in both adult cats and kittens. Previous investigators had been able to reproduce the condition by blocking the intraventricular passages of the cerebrospinal fluid; in this laboratory the experimental obstruction to the normal escape of the fluid was caused by a lesion in the meninges and not by blockage in the ventricular system. The method used for this purpose was the injection into the subarachnoid space of a 5 to 10 per cent solution of lampblack in Ringer's solution. The carbon particles thus introduced either mechanically blocked the meningeal passages of the cerebrospinal fluid or occasioned a sterile meningitis which, in turn, accomplished a similar obstruction.[2]

Such subarachnoid injections of suitable amounts of lampblack in adult animals caused an almost immediate lethargy and sleepiness; the more acute cases remained in this condition for several days. In the milder cases the animals were a little more quiet than normal, with the progressive development of a lethargy. The lesion at autopsy in such adult cats was a typical hydrocephalic enlargement of the lateral ventricles.

The younger animals (kittens), in which the ossification of the skull was not yet complete, showed even more striking abnormalities after such injections of lampblack. Not only did the ventricles enlarge enormously at the expense of cerebral cortex, but the whole head became bulging and relatively enormous. The fontanelles opened widely; in some animals in which the cranial bones were already united by bony union, the fontanelles were re-formed. The clinical and pathological pictures were typically those of an infant with an internal hydrocephalus.

As soon as it was found possible to reproduce this pathological condition invariably, therapeutic measures aiming at its relief were undertaken. A certain degree of amelioration followed the creation of an artificial connection between the subarachnoid space and the superior sagittal sinus.

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[a] Report of Investigations conducted at the Army Neurosurgical Laboratory, Baltimore, Md. By Capt. Lewis H. Weed, M. C.

CISTERN PUNCTURE[3]

Difficulty in obtaining cerebrospinal fluid by lumbar puncture in laboratory animals led to the adoption of puncture through the occipitoatlantoid ligament as a convenient method (Dixon and Halliburton). The technique for performing this puncture proved to be quite simple, and with a little practice the needle may be inserted into the fluid reservoir, lying just beneath the ligament, without injury to the structures of the medulla. The use of this operation greatly facilitates the obtaining of spinal fluid from the cadaver. It should prove of value in man when there is a block in the spinal subarachnoid space due to meningitic adhesions; it should be serviceable likewise in irrigations of the spinal subarachnoid space for the removal of the pus and débris due to infection. With the increase in experience in the use of this puncture the route may prove of value for the introduction of serum in early cases of epidemic meningitis. It was found that a much better spread in the basilar cisterns and over the convexity of the brain was obtained when a suspension of india ink was injected by the occipitoatlantoid route than when it was introduced in the lumbar region.

EFFECT OF INTRAVENOUS INJECTIONS OF SOLUTIONS OF VARIOUS CONCENTRATIONS UPON CEREBROSPINAL FLUID PRESSURE[4]

Research in the Army Neurosurgical Laboratory demonstrated that the intravenous injection of hypertonic solutions exerted a marked effect on the pressure of the cerebrospinal fiuid. Hypotonic solutions, when injected intravenously into an etherized animal, caused an enduring rise in the pressure of the fluid as determined in a manometer connected with the subarachnoid space. On the other hand, the intravenous injection of a strongly hypertonic solution brought about an initial rise in the pressure of the cerebrospinal fluid followed quickly by a marked fall, often to negative values. The employment of a solution isotonic with the blood occasioned no lasting change in the pressure of the cerebrospinal fluid. The logical explanation of the alterations in the pressure of the cerebrospinal fluid following the intravenous injection of hypotonic and hypertonic solutions, seems naturally to be related to the experimental change in the osmotic value of the blood. Data regarding the absolute or relative osmotic values of the body fluids were not obtained, but it appeared that the alteration in the salt-content of the blood produced experimentally could only be compensated by fluid readjustments within the tissues.

ALTERATION OF BRAIN VOLUME.[5]

Investigations on cats showed that the intravenous injection of a strongly hypertonic solution (30 per cent NaCl or saturated $NaHCO_3$) was followed by a marked decrease in the size of the brain. This change in cerebral volume occurred in the unopened skull; but if the skull was trephined and the dura opened, the brain after such injection could be seen to fall away several millimeters from the inner surface of the skull. Intravenous injection of a hypotonic solution (water) caused a marked swelling of the brain. Such increase in brain bulk was noted in the intact cranium; if the skull was opened, tense herniæ of the cerebral substance, protruding several millimeters, invariably

resulted from the experimental procedure. Animals subjected to these experimental procedures promptly became normal on recovery from the anesthetic.

These changes in brain bulk were independent of the volume of the fluid injected, as was demonstrated by control injections of Ringer's solution, which did not alter the size of the brain. The age of the animal was found to play a noticeable part in this phenomenon, the brains of old cats failing to respond readily to such intravenous injections, especially of hypotonic solutions. No histological changes were demonstrated in the brains of animals subjected to experimental alteration of brain bulk but with opened skulls (removal of restrictions to change in volume). In those animals which were not trephined, internal changes, recognizable microscopically, were found quite constantly. The clinical application of this phenomenon of volume-change of the brain should be of value in cases of increased intracranial tension, cerebral herniation, cerebral edema in acute infections or injuries.

BRAIN ABSCESS [6]

The methods by which brain injuries and local infections were produced in experimental animals varied much in detail, but the investigation was primarily related to the study of the general principles underlying the spread of infection and the possibility of the experimental control of the process. In every instance the dura was perforated; in some of the experiments, parts of the cortex were removed; in others, perforations communicating with the lateral ventricles were made, while in others only the most superficial layers of the brain were injured. Foreign bodies of bone or metal were sometimes introduced into the wound; while at other times the skull was fractured, with puncture of the central nervous system. In a word, attempts were directed toward reproduction of cerebral wounds similar to those occurring at the battle front. It was early discovered that an abscess in the brain of a cat developed only with great uncertainty unless a massive dose of bacteria was introduced into the wound. Simple puncture wounds were found to heal per primam although no efforts were made to sterilize the instruments or tract. The animal's resistance to infection even after puncture of the dura seemed quite remarkable. Gross examination of such infected brains showed principally great swelling, with necrosis of the tissue and protrusions through the wound opening. In about one-half of the cases recorded a generalized meningitis was present at death, either from direct or indirect infection of the lateral ventricles in the region of the wound and subsequent spread to the meninges through the foramina of Magendie and Luschka. A complete restoration of the destroyed nervous tissue was never attained, although function might have been taken over by other cells; and in some instances a normal individual, to all intents and purposes, was preserved. An attempt was made by the tissue to combat the process of destruction instituted by the infecting organism; this defense, as well as the removal of the débris by large phagocytic cells, could be seen microscopically. The tendency of the infective process to invade the subarachnoid space from the point of injury was not marked, but in a third of the animals the infection entered the subdural space, forming there a subdural abscess.

These acute traumatic lesions were very different from the more slowly growing abscesses, extending from the cranial air sinuses. The latter, occurring frequently in man, may be differentiated by the relatively slight swelling and dislocation of the cerebral substance, and by the development of a definite connective tissue capsule between the infective focus and the sound parenchyma. The traumatic abscess in the experimental animal extended rapidly along the fiber tracts. No encapsulation could be demonstrated in any of the observations. Healing took place by the ingrowth of connective tissue.

ACTION OF ANTISEPTICS UPON THE CENTRAL NERVOUS SYSTEM [7]

The toxicity of certain antiseptics upon the central nervous system was tested by direct injections into, or irrigation of, the subarachnoid space. Practically all of the chemical bodies employed possessed definite intraspinous toxicity, so that, unless given in suitable dilution and amount, immediate death of the animal ensued. With chloramine and flavine on subarachnoid injection, in addition to the initial toxicity, death in five to ten days was brought about in consequence of the direct injury to the central nervous system. With injection of small amounts of a suitable dilution the animals remained apparently normal but all showed at autopsy pathological changes in the meninges. The lesions consisted of a more or less complete obliteration of the meningeal (subdural and subarachnoid) spaces with serofibrinous exudate; in the more severe cases the nervous system became involved in a process of destruction by direct continuity from the meninges. The blocking-off of the subarachnoid space by this exudate was complete in one case, as demonstrated by the subsequent injection of india ink; it was not, however, sufficient for the localization of an infection. The subarachnoid injection of lysol and potassium permanganate, in the presence of an otherwise fatal meningeal infection, did not prolong the life of the animal.

SUBARACHNOID IRRIGATIONS [8]

In the earlier experiments the irrigation was limited to the spinal canal, and for this operation the first puncture needle was inserted into the subarachnoid space through the occipitoatlantoid ligament, and the second in the lumbar region. Between these needles fluid could be passed through the spinal subarachnoid space in either direction, although the descending route (from cervical to lumbar) was, as a rule, selected. Later, in order to include the cerebral meninges in the irrigation, needles were introduced into the subarachnoid space in the vertex area; from there the flow could be conducted either to an occipitoatlantoid or to a lumbar needle.

Irrigations of the spinal and cerebral subarachnoid spaces were well tolerated by cats if the irrigating fluid was composed of sodium chloride, potassium chloride, and calcium chloride in proper proportions (modified Ringer's solution). If, however, the irrigations were made with isotonic solutions of sodium chloride alone, various toxic effects became very apparent. Many of these animals died during or immediately after the irrigation; if this immediate toxicity was survived, convulsive seizures and acute mania were almost invariable. Recovery from such attacks was frequent. Single irrigation of infected

meningeal spaces with modified Ringer's solution prolonged the life of the animals as compared with the controls. The period of survival in many cases was doubled as a result of this washing out of the infected meninges. Multiple irrigations were not attempted.

EPIDURAL COMPRESSION OF THE SPINAL CORD [9]

The method employed to produce compression of the cord was the injection of paraffin into the epidural space; subsequently the spinal fluid above and below the area of compression was examined. As a result of such epidural compression of the spinal cord a partial transverse myelitis, manifested chiefly as incomplete paraplegia, resulted. In these cats the spinal fluid obtained from below the area of compression usually differed greatly from that above; the former showed almost constantly a greater protein-content, was usually scanty in amount, and frequently of a yellow color, and at times clotted rapidly and completely. The fluid taken from above was uniformly normal. As in man, the fluids which clotted and contained the greatest amount of protein were found in the animals showing greatest symptoms of pressure upon the spinal cord. The protein associated with the mild aseptic meningitis present in these cases was relatively insignificant as demonstrated by the fact that the fluid, obtained from the cisterna magna, often contained white cells equal in number to those from the lumbar region, but showed only slight increase in protein. In some cases a well-marked vascular engorgement of the pial vessels below the area of compression was demonstrated as was also an abnormal amount of serum in the subarachnoid space at the level of compression. Transudation into the lumbar sac was apparently the pathological process operative in the formation of these fluids so rich in protein.

EXPERIMENTAL CRANIOPLASTY [10]

Experiments were undertaken to determine the relative value of various kinds of bone for bridging experimental defects in the skull, the protection of the underlying structures, and the return of the contour of the head to its normal convexity. The problems of cranioplasty could not be met entirely by the experience obtained from osteoplastic work on long bones. The logical material for use in cranioplasty consisted of plates of cranial bones as the requirements of protection for the brain and restoration of the shape of the head could be immediately accomplished and the formation of exostoses was avoided. Animal experimentation (on cats) indicated that either living or dead grafts could be used effectively in the head. In the case of dead grafts, the bone might be removed during routine autopsies, sterilized by boiling or in the autoclave, and kept until needed for the operation. In man living grafts were recommended; but if they were not available, plates of sterilized cranial bone were preferred to any other tissue.

LETHARGIC ENCEPHALITIS [11]

The initial investigation of an outbreak of lethargic encephalitis in Camp Lee, Va., was intrusted to the staff of this laboratory. Nine cases of this disease were examined, with complete pathological studies of four. The onset of

symptoms was always insidious—headache, malaise, weakness, and vertigo being commonly complained of. Early symptoms of probably greater significance were sore throat, diplopia, and invariable fever. It was unusual to find signs of organic nerve disease in the first week of illness, but by the second week—sometimes later still—a widespread organic neurological disorder became evident, when cerebral symptoms appeared. Drowsiness occurred in almost every case, frequently developing into coma, and at times alternating with a state of irritability or anxiety. In spite, however, of an apparently clouded mental condition, orientation and cerebration were usually unaffected, until just before death. Long projection fiber tracts to arms and legs showed profound disturbance in seven cases as indicated by ataxia, spasticity, and clonus. The only symptoms and signs of a focal character were referable to the brain stem, and these were present in all. Diplopia was complained of in seven of the nine cases, although oculomotor palsy was seldom seen, doubtless because of its transitory nature. The second most frequent disorder was weakness of the facial muscles, usually one-sided, a condition seen in five cases.

Macroscopically, all the brains examined appeared alike. A great degree of engorgement of all vessels was conspicuous, and free blood was present in the meninges as evidenced by a pink tint to the pia. The chief seats of the lesions were the brain stem and basal ganglia. The essential pathologic processes were found to be a perivascular exudation and a diffuse infiltration of parenchyma. While both types of lesion varied greatly in intensity, extent, and symmetry, they occurred especially in the gray matter about the canal, fourth ventricle, and aqueduct, though deeper tissues were also affected and the white matter was not spared. The cells concerned in both types of lesion were all mononuclear; a small mononuclear cell and a large mononuclear cell, frequently phagocytic, together with the lymphocytes and plasma cells, were recognized. Polymorphonuclear leucocytes were absent even in the cases of short duration. That the diffuse infiltrating exudate was not necessarily related to a destructive process was borne out by the normal or only slightly changed appearance of nerve cells in its midst; however, when the exudate was excessive, marked nerve cell changes, including neuronophagia, resulted. Hemorrhages were few in number and very small. Blood vessel changes were of two types. There was almost constant evidence of proliferation of the intima in vessels in areas of exudation, those in unaffected territory usually showing no abnormality. The second type of lesion noted was infiltration of the vessel walls (especially intra-adventitial), with mononuclear cells, chiefly lymphocytes and plasma cells. The cord and organs in cases examined appeared essentially normal. Lesions in the cerebral cortex were in all cases either nonexistent or negligible. No organisms were seen and cultures from the cerebrospinal fluid and from the nervous system post mortem were negative.

EXPERIMENTAL MENINGITIS

One of the chief problems presented for investigation in the Army neurosurgical laboratory was that of meningitis. In general it was not proposed to deal with the meningococcic infections but rather to ascertain whether the pyogenic, nonmeningococci forms of meningitis could be treated successfully

by measures other than serum therapy. The first need in such an investigation was that of standardization of the infection; i. e., the experimental production of a uniformly fatal meningitis. It was hoped that an organism capable of bringing about meningeal infections in the laboratory animals in numbers analogous to those causing infection in man could be found. Previous work on meningitis in animals had, almost without exception, dealt with the subarachnoid injection of very large doses of organisms (one-half to four agar slants). The infections under such circumstances were hardly uniform, even in the monkey.

The search in this laboratory for an organism highly virulent within the meninges of experimental animals was successful. The investigation necessitated the testing of many strains of bacteria within the meninges and the later accentuation of the pathogenicity of those which possessed "natural virulence." Later the major portion of the work became centered about the study of the factors which favored the invasion of the meninges from the blood stream; the production of such hematogenous meningitides was investigated from many angles. The results of the subarachnoid injection of the various organisms will be detailed first and the study of infections of the meninges by organisms circulating within the blood stream will be given later.

MENINGITIS PRODUCED BY SUBARACHNOID INOCULATION[12]

Practically all of the experiments dealing with the direct subarachnoid injection of organisms were done on cats, the inoculations being made into the meninges through the occipitoatlantoid and lumbosacral ligaments. Organisms, possessing no natural virulence within the meninges of the cat, were discarded after a few trials. If the organism seemed to possess some pathogenicity, but too large a number, on initial injection, was required to produce a fatal meningitis, the virulence was raised by passage through the meninges of a series of animals.

The reaction caused by the growth of an organism in the meninges was determined by the clinical manifestations of the animal, characteristic changes in the cerebrospinal fluid, and the pathological lesions of the central nervous system at necropsy. Although the clinical manifestations varied somewhat, the more acute cases were characterized by general weakness, convulsions, extensor rigidities of the muscles, accompanied by frequent spontaneous outcries. These signs of cortical irritation appeared in paroxysms, so that, were the animal observed during a quiescent period, little could be noted unless the reactions were elicited by appropriate stimuli. Chronic meningitis exhibited signs of neuromuscular disturbance—ataxia, variations in gait (spasticity), weakness and paralysis of certain muscle groups—which were probably the result of permanent destructive lesions in the central nervous system.

The microorganisms which generally cause a fatal meningitis in man (meningococcus, pneumococcus, streptococcus, staphylococcus, influenza, etc.) were found to possess but slight natural pathogenicity for the meninges of a cat. This animal also proved to be comparatively insusceptible to these organisms on intravenous inoculation, especially if they were of human origin. Another group of organisms (miscellaneous bacilli) was found to be capable

of the production of a fatal meningitis upon the injection of massive doses into the subarachnoid space, but their virulence could not be raised markedly. A third group of organisms was found to possess great virulence within the meninges of the laboratory animals used. Of this group (*B. pyocyaneus*, *B. coli*, *B. paratyphosus-B.*, and the mucosus capsulatus group) a strain of *B. lactis aerogenes* possessed the greatest natural virulence for the meninges. The chief disadvantages of this organism were related to its extreme virulence, the difficulty experienced in producing an immune serum, and its relative infrequency as a meningeal invader in man; these characteristics made it difficult of use in the investigation of certain other phases of the study of experimental meningitis, although for the purpose of this laboratory it was invaluable. This strain of *B. lactis aerogenes* was virulent within the meninges of all the common laboratory mammals; in cats, the subarachnoid injection of as few as 20 organisms (as determined by plating) produced a meningitis causing death within 24 hours. The organism was originally obtained at autopsy from the heart's blood and lungs of a man dying of bronchopneumonia.

The routine culturing at necropsy of the heart's blood of animals dying of experimental meningitis revealed certain interesting facts in regard to the transfer of infection between the meninges and the blood stream. In all cases of meningitis caused by the injection of organisms into the subarachnoid space, cultures of heart's blood showed the presence of the same bacteria with which the animal had been inoculated intraspinously.

THE PATHOLOGY OF EXPERIMENTAL MENINGITIS [13]

The study of the meningeal reaction produced by subarachnoid inoculation of a large number of organisms, was made largely upon formalin-hardened material. The meningitis resulting from such subarachnoid inoculation could be grouped into three pathological types. The first, a focal subacute meningitis, showed small accumulations of exudate in isolated foci, especially in the deeper layers of the pia. Organisms were usually absent from the meninges and the blood, both culturally and on microscopic examination. The second, an acute, low-grade, exudative meningitis, was characterized by a scanty or a considerable exudate, of polymorphonuclear or lymphocytic cells. Organisms, if present, were but few in number and were considered to possess only mild subarachnoid virulence. The third group consisted of those cases of massive acute meningitis, in which there was evidence of extreme virulence and proliferation of the organism. In this type alone was death considered to be due primarily to the meningitis.

In the cases of acute fulminating meningitis the exudate soon passed beyond the subarachnoid space into the ventricles, and a little more tardily invaded the substance of the brain and spinal cord. In 24 hours approximately one-half of the specimens showed such involvement of the central nervous system; this invasion usually occurred by direct extension from the ventricles and canal. The exudate also spread outward with the nerve roots, and a patchy or diffuse epidural infection then resulted. The dura itself became infiltrated at areas of root "perforation." The blood stream was early infected in such acute

meningitis, as seen on section and on culture, and it is likely that this septicemia played an important rôle in the death of the animal. In the less acute forms of meningitis, the arachnoid membrane more or less effectively limited the spread of infection from without and from within.

FORMATION OF MACROPHAGES BY THE CELLS LINING THE SUBARACHNOID CAVITY[14]

In the course of the study of the processes involved in the localization of an infection within a focus in the nervous system, certain physiological reactions of the cells lining the subarachnoid space were noted. When active or inert particles of matter were injected into the subarachnoid cavity of a living animal, the cells lining the space hypertrophied, lost their normal attachments, and engaged in removing the débris. The importance of such a formation of free cells from fixed elements in any process involving destruction and repair in the meninges (infection, hemorrhage, etc.), seemed great. The reaction of the cellular membrane to such particulate matter was a slow one and appeared to be well under way only after the first 24 hours; dead bacteria might be taken up and removed by the leucocytes before the arachnoid cells showed any signs of activity. The most striking results occurred after subarachnoid injection of laked blood, due probably to the fact that it had no toxic effect on the cells and could be utilized by them.

This reaction of the cells lining the subarachnoid space apparently plays a part in the defensive process against infection. Many of the earliest cases of meningitis (six hours) showed a marked proliferation of these cells; the exudate frequently was largely mononuclear. In other cases roughly half of the cells were mononuclear while the remainder were polymorphonuclear. On section, the cell borders of the arachnoidea (particularly the trabeculæ) seemed to be high and proliferating; the origin of at least a considerable portion of the mononuclear elements in the exudate seemed certain. The proper control of such a defensive cellular reaction will ultimately accomplish much in the therapy of infectious processes.

THE CEREBROSPINAL FLUID IN MENINGITIS[15]

In meningeal infections there is always a cellular and protein exudate in the cerebrospinal fluid. With different bacteria and etiological factors, such pathological conditions within the meninges cause also variations in the concentrations of glucose, of sodium chloride, and of urea, and perhaps other changes both in organic and inorganic constituents. The increased cellular and protein constituents of the cerebrospinal fluid must, however, be considered as giving greatest indication of a reaction caused by the injection of a known micro-organism into the subarachnoid space.

The number of cellular elements in the normal cerebrospinal fluid of the experimental animals was found to be rather variable; in a series of routine examinations the counts of the white cells ranged from 0 to 10 per c. mm. No erythrocytes were demonstrated in the cerebrospinal fluid from normal cats in a large number of examinations. The protein content varied from 0.1 to 0.5 grams per liter, 0.25 grams being a low normal and 0.5 grams a high, border-

ing on a pathological fluid. The colloidal gold reaction of a number of normal fluids gave a similar curve to that obtained by normal fluids from man. In acute meningitis the cerebrospinal fluid of the cat was found to contain from 200 to 22,400 white blood cells, 2 to 17 grams of protein to a liter, and to give a reaction in any of the three zones in the gold sol test. The cerebrospinal fluid of chronic meningitis in a cat proved to be practically normal, with exception of the gold sol reaction, in which a change to the paretic or luetic zones was recorded. In some of the chronic cases there was a slight increase in the number of white blood corpuscles and in the content of protein. The colloidal gold reaction was of service in demonstrating a pathological cerebrospinal fluid but showed no specific zone reaction, except to a slight extent in the cerebrospinal fluids from animals with chronic meningitis. There was indeed a great similarity in the Lange test as applied to the cerebrospinal fluids from cases of experimental chronic meningitis and those of general paresis in human patients. It was suggested that reaction in the paretic or even the luetic zone denotes the presence of a small amount of protein, as in a chronic lesion of the central nervous system.

INTRAMENINGEAL VIRULENCE OF MICROORGANISMS[16]

In determining the natural virulence of 102 strains of 24 groups of microorganisms, it was found that certain bacteria or groups of bacteria were more capable than others of producing a fatal infection when injected directly into the meningeal spaces. The term "natural" virulence has been used to denote the pathogenicity of recently isolated strains of microorganisms, before increase in virulence by animal passage. It was found necessary to enhance the natural intrameningeal virulence of strains of *B. mucosus capsulatus*, hemolytic streptococcus, meningococcus and *B. paratyphosus*, as after being kept for some time on the ordinary laboratory media their virulence so far decreased as to render them of little value for experimental work. Failure to increase the intrameningeal virulence (though the intravenous pathogenicity was raised considerably) by successive intravenous injections of the culture in cats caused the trial of "animal passage" by means of inoculation directly into the meninges. It was found possible by this method of direct subarachnoid inoculation to increase the virulence of four strains of microorganisms, representing as many groups, to the degree indicated: *B. lactis aerogenes*, 0.000,000,000.01 c. c. of a 24-hour broth culture killing in 24 hours (cats); *B. paratyphosus-B.*, 0.0001 c. c. (cats); hemolytic streptococcus (cats), 0.001 c. c., and (rabbits), 0.0005 c. c.; meningococcus (rabbits), 0.001 c. c. By such passage, the intravenous virulence was hardly increased; the intrameningeal and intraperitoneal virulence increased to the same degree. By combined intraperitoneal and intrameningeal methods, approximately the same degree of pathogenicity was developed with streptococcus in rabbits. The intrameningeal virulence became at least 500 times greater than the intravenous. The ratio of the intrameningeal and intravenous pathogenicity of *B. lactis aerogenes*, of *B. paratyphosus-B.*, of streptococcus on cats and on rabbits, and of meningococcus became, respectively, 10,000,000 to 1; 10,000 to 1; 1,000 to 1; 500 to 1, when the intrameningeal method of animal passage was employed.

HEMATOGENOUS MENINGITIS[17]

The marked virulence of the *B. lactis aerogenes* within the meninges of the cat led to its use in other laboratory mammals. For all of these (guinea pig, white rat, rabbit, monkey) the same intraspinal pathogenicity held. Later, experiments leading to another end were undertaken. These concerned the intravenous injection of this organism in doses of from 0.5 to 1 c. c. of a 24-hour broth culture. None of these cats developed meningitis, but remained normal throughout the period of observation. In one case, shortly after such experimental injection into the blood stream, cerebrospinal fluid was removed by puncture. The next day the animal showed signs of meningeal irritation, and a second puncture, with withdrawal of cerebrospinal fluid, was made. This fluid was definitely turbid, contained 5,800 white blood cells, and yielded a positive culture of *B. lactis aerogenes.* In the film preparation from this fluid many bacilli were present. The animal died in 28 hours, and at necropsy a typical exudative meningitis was found.

Experiments on cats were immediately devised to test out the possible relationship of this withdrawal of cerebrospinal fluid during an artificial bacteremia to the later production of a meningitis.[18] The series were so arranged that the control animals were given double the intravenous dose of *B. lactis aerogenes* (usually 0.5 c. c. of a 24-hour meat infusion broth culture). These control cats remained normal and showed no signs of meningeal infection, and were usually killed at the end of a month for histologic control. The other cats in the series were given the unit dose of organisms intravenously (usually 0.25 c. c. of the same culture), and two minutes afterward, cerebrospinal fluid was withdrawn. In the routine experiment, from 1 to 2 c. c. of fluid was permitted to escape, and the animal then allowed to recover from the anesthetic. As contrasted the next day with the control cat, which, though receiving double the intravenous dose, was normal and active, the punctured cat would exhibit signs of meningeal infection. Customarily within 24 hours, the typical signs of such meningeal involvement were present; the animal was somewhat hypersensitive, ill, and cautious, and moved only on urgent necessity. The tendency toward convulsions became more outspoken as time elapsed, and spontaneous seizures were noted. During such a spasm death often occurred, or the animal went into a coma and died without further signs of meningeal irritation. Pathologically, an acute exudative leptomeningitis was invariably found.

The experimental procedure outlined above was repeated in scores of animals; the production of meningitis by intravenous inoculation followed by release of cerebrospinal fluid was so certain and so regular that it became the chief method for the experimental production of the infection. The work was controlled in many ways, in addition to the routine method of giving one animal in the series an intravenous injection of double the amount of the culture but without puncture.

The release of cerebrospinal fluid was brought about by either lumbar or occipitoatlantoid puncture. Approximately the same amount of fluid was withdrawn by either method; the end result was identical. Release of fluid by both procedures, with proper dosage of the organism within the blood stream, resulted invariably in infection of the meninges.

That this phenomenon of an acute meningitis following intravenous inoculation with release of cerebrospinal fluid was not peculiar to cats was demonstrated by a series of experiments on rabbits, guinea pigs, white rats, and monkeys. In each of these species, the control was given the same or double the intravenous dose as the animal from which the cerebrospinal fluid was removed at the height of the artificial bacteremia. In every case, the control remained well and normal until killed, while the animals from which spinal fluid was removed promptly developed a typical meningitis with death in 96 hours or less. In the two monkeys at our disposal, the same procedure was carried out; the control (receiving only the intravenous injection) remained normal for seven months, while the monkey receiving the intravenous injection, followed by release of cerebrospinal fluid, died in 54 hours with typical signs of meningitis. The two monkeys were subjected to cistern puncture 48 hours after the initial injection; in the control, the cerebrospinal fluid contained no white cells and the culture was negative, while the fluid of the other had 14,000 white blood cells and gave a positive culture.

The time relations between the withdrawal of cerebrospinal fluid and the intravenous injection of organisms were found to be of importance. In no case did meningitis develop when the cerebrospinal fluid was released 30 or more minutes before the intravenous inoculation. If the puncture were done, however, only a few minutes before the inoculation into the blood stream, infection of the meninges occurred as in other observations in which routine withdrawal of fluid was accomplished immediately after the intravenous injections of organisms.

During the height of a suitable artificial bacteremia, the release of spinal fluid invariably caused a meningitis. In one series of experiments, the punctures were delayed for various periods after the intravenous injection. Animals from which cerebrospinal fluid was removed within three hours after the intravenous injection developed meningitis. But also animals receiving somewhat larger intravenous doses could not be punctured five hours afterwards without developing infection of the meninges. Hence a striking time relation between the degree of the artificial bacteremia and the withdrawal of cerebrospinal fluid seemed established. It must be assumed that following the intravenous injections of *B. lactis aerogenes* the number of bacteria in the circulating blood was constantly diminishing so that in practically all cases of simple intravenous injection the blood was sterile in 24 hours. Consequently delay in removing cerebrospinal fluid became comparable to the initial administration of a smaller intravenous dose of organisms. Apparently the number of organisms circulating in the blood stream at the time of puncture is one of the crucial factors in determining the infection of the meninges.

Other observations were made to determine how soon the infection of the meninges occurred after the release of cerebrospinal fluid during the height of the bacteremia with *B. lactis aerogenes*. In these typical experiments the animals were killed in one hour, two hours, four hours, and six hours after the injection and puncture. The membranes of the central nervous system were then examined in the fresh by means of smears taken from the subarachnoid space, and the findings later controlled by histologic sections. In the one-hour

case, after repeated search one or two large bacilli, morphologically identical with *B. lactis aerogenes*, were found in the cerebral leptomeninges but not elsewhere within the meninges. The two-hour specimen yielded bacteria only in the cranial portion of the pia-arachnoid, but in considerable numbers. Practically no cellular exudate was found. Many polymorphonuclear and mononuclear cells were present in the four and six hour animals; the infection seemed to be largely within the cerebral meninges, but apparently to a lesser degree the spinal portion of the subarachnoid space was involved. These findings indicated that the infection of the meninges occurred almost immediately after the release of cerebrospinal fluid during the bacteremia.

Pathologically, the meningitis produced by this means was comparable to infection of the meninges in man. In a great majority of cases (particularly those under 48 hours' duration) the gross distribution of the exudate was almost entirely cerebral; but in a small percentage of the early cases, the exudate was wholly confined to the spinal meninges. In the more prolonged infections, the involvement of the subarachnoid space was customarily universal. Microscopically the exudate consisted of polymorphonuclear leucocytes, large mononuclear cells, a few phagocytes, and the infecting organisms.

It was essential to determine whether the meningitis produced by intravenous inoculation and release of cerebrospinal fluid was the result of infection due to a possible leakage of blood along the track of the needle into the subarachnoid space. The evidence was strongly in favor of the idea that the determining factor in the infection was the reduction of the pressure of the cerebrospinal fluid, with associated vascular changes.

With such results following the intravenous injection of *B. lactis aerogenes* with release of cerebrospinal fluid, experiments were undertaken to ascertain if the same procedure, but with other organisms, would produce meningitis. The difficulty here was that with the ordinary cultures in a laboratory, the intravenous toxicity was high in comparison to the intraspinal. However, it was possible to repeat these experiments and confirm the finding on the cat with two other organisms, *B. pyocyaneus* and *B. paratyphosus–B.* On rabbits a similar result has been obtained with strains of meningococci and of streptococci, procured from an Army camp.

The facilitation of infection of the meninges from the blood stream by the release of cerebrospinal fluid seemed established as a biological factor by the production, in this laboratory, of a typical meningitis with five different organisms. The conditions for the successful production of such an experimental meningitis concerned two factors, both apparently of determining importance. In the first place, it was demonstrated that the organism used must possess relatively great virulence within the meninges and be capable of multiplication there, even when in small numbers. The strain of *B. lactis aerogenes* best fulfilled this requirement when introduced into the subarachnoid space of the common laboratory mammals; its virulence in these animals was comparable to that of organisms causing meningitis in man. The other important condition dealt with the number of organisms circulating in the blood stream at the time of release of the cerebrospinal fluid; if this was not great enough, no infection took place.

It must not be assumed from the statements made that a meningitis could not be produced by *B. lactis aerogenes* after simple intravenous injection. Such a meningitis was caused by the introduction within the blood stream of massive doses of the organism. The amount necessary to produce such a meningitis was many times the customary intravenous injection; such animals were killed usually by the septicemia and not by the meningitis. Many of these animals died from the overwhelming intravenous injection without development, as shown by later necropsy, of any meningeal infection at all.

Practically all of the data indicated that the infection of the meninges by organisms circulating in the blood stream, following removal of cerebrospinal fluid, was due to alteration in the pressure of the cerebrospinal fluid and the associated vascular changes within the cranium. It was assumed that the withdrawal of the spinal fluid was partially compensated by an immediate vascular dilatation, particularly on the venous side. This vascular readjustment really involved a slowing of the blood flow through the cerebral vessels; it was thought possible that this slowing of the flow might facilitate ingrowth of organisms from the blood stream into the meninges.

Experiments to test this hypothesis were carried out.[19] In the first group, the retardation of cerebral blood flow was brought about by digital compression of the jugular veins and adjacent tissues of the neck for two minutes; in the second series, the heart was completely stopped for 30 seconds by excessive administration of ether. Both series were subjected to the necessary controls; every animal was given a suitable intravenous injection of organisms before the secondary facilitating procedure was carried out. In the two series, a fatal meningitis occurred in 50 per cent of the animals; the clinical manifestations of the disease were typical.

These experiments seemed to indicate strongly that the infection of the meninges from the blood was closely associated with cerebral vascular changes. That only one-half of the animals developed a fatal meningitis could well be accounted for by the necessary variability of the experimental procedures employed. It did appear, however, that the removal of the cerebrospinal fluid was more certain than these other procedures as a facilitating factor. At this time, experiments dealing with the effect of intravenous injections of solutions of different concentrations upon the pressure of the cerebrospinal fluid were being conducted in this laboratory. It was found, as recorded in a foregoing paragraph, that the intravenous injection of a strongly hypertonic solution markedly lowered the pressure of the cerebrospinal fluid, often to negative values. Such intravenous injections were immediately combined with suitable intravenous injections of organisms, virulent within the meninges; a fatal meningitis invariably occurred as in the experiments in which the pressure of the cerebrospinal fluid was reduced by withdrawal of fluid. The relation of the low pressure of the cerebrospinal fluid and its associated vascular changes was thereby demonstrated.

Further observations were made to determine the effect of preliminary subarachnoid injections of protein (autologous, homologous, and heterologous) upon the intrameningeal lodgment of organisms circulating within the blood stream. Flexner and Amoss had earlier demonstrated that poliomyelitis

could be experimentally produced by intravenous injection of the virus, provided that the permeability of the meninges had previously been altered by intraspinous injection of serum, salt solution, etc. Subsequently Austrian applied this same procedure to experimental meningococcic meningitis in rabbits. Austrian recorded the production of a fatal meningitis in three out of twenty rabbits given intravenous injections of meningococci after preliminary intraspinous injections of serum. In this laboratory preliminary injections of serum into the subarachnoid space were given and later suitable intravenous injection of *B. lactis aerogenes* was made. In 6 out of 39 cats, a typical fatal meningitis was produced; the other animals remained normal in every way. As a facilitating mechanism the preliminary subarachnoid injection of serum has been found to be by no means as effective as the reduction in the pressure of the cerebrospinal fluid and the associated vascular changes.

The interpretation of these many and varied experiments is necessarily related to the mechanism of facilitation of the infection of the meninges from the blood stream. The intravenous injection of suitable dosage of an organism virulent within the meninges did not of itself produce meningitis; such an injection had to be combined with an experimental procedure which facilitated invasion of the subarachnoid space by bacteria. Of these various procedures, withdrawal of cerebrospinal fluid by puncture or reduction of its pressure by intravenous injection of strongly hypertonic solutions was most efficacious. Measures slowing the intracranial blood flow (cerebral venous congestion or stoppage of the heart) caused infection of the meninges in only half of the cases. Preliminary subarachnoid injections of serum resulted in infection of the meninges in but 6 out of 39 experiments.

Pathology of Hematogenous Meningitis[17]

In this acute hematogenous meningitis, there occurred a more or less widespread distribution of purulent matter throughout the subarachnoid space, obliterating all characteristic markings and obscuring contours. With the discoloration due to pus and hemorrhage, there was associated a fairly constant swelling of the nervous system itself, rendering tense the dura of both brain and spinal cord. In a great majority of cases (particularly those under 48 hours' duration) the gross distribution of the exudate was almost entirely cerebral; but in a small percentage of the early cases, the exudate was wholly confined to the spinal meninges. Evidence favored the view that the cortical meninges were the site of earliest infection, with rapid spread to other portions of the subarachnoid space and to the cerebral ventricles. The invasion of the ventricles occurred early in all fatal cases. Infection of the ventricles and canal led to involvement of the substance of the brain and cord. The exudate which accompanied all the meningeal infections was polymorphonuclear or mononuclear in character and its distribution followed closely that of the organisms. In the earlier cases, the exudate was often slight, but in those of longer duration it became massive, imparting to the entire meninges a discolored appearance. Extension outward from the subarachnoid space occurred in many cases and two methods of the accomplishment of this process have been observed. One was through apparent adhesions of arachnoid and dura with infiltration by

leucocytes and swelling at this point. A more common site of extension was in the area where the dura is "pierced" by the nerve roots, the exudate frequently accompanied both the anterior and posterior roots outward for a short distance, invading the dura and sometimes passing through it to its external surface. With the strains of *B. lactis aerogenes*, meningococcus, and streptococcus employed, there was produced an acute hemorrhagic-purulent meningitis, in which the bacteria appeared to be rapidly increasing in number. With *B. pyocyaneus* and *B. paratyphosus-B.*, a mild acute meningitis resulted, with very few organisms to be seen. Control animals receiving inoculations alone showed no pathological lesion of the central nervous system or merely a mild "febrile reaction," recognizable only microscopically.

PRODUCTION OF PANOPHTHALMIA BY INFECTION FROM THE BLOOD STREAM.[20]

The microorganism, *B. lactis aerogenes*, which proved so extremely virulent in the central nervous system, exhibited a similar pathogenicity for the eye. The release of fluid from the anterior chamber of the eye, and the congestion of the cerebral circulation during an experimental bacteremia, resulted in the production of a purulent panophthalmia. It is interesting, however, that in the course of several hundred experiments on meningitis in which this bacterium was inoculated into the blood stream of cats, an ophthalmia was produced only once. When procedures analogous to the withdrawal of spinal fluid were carried out on the eye, the infection was limited to the one organ operated upon, the opposite eye and the central nervous system being unaffected. The close correspondence between the anatomical and physiological processes in the eye and central nervous system was emphasized by this production of panophthalmia by intravenous inoculation followed by facilitating measures.

LUMBAR PUNCTURE AS A FACTOR IN THE CAUSATION OF MENINGITIS[21]

A series of cases was observed in the base hospital at Camp Jackson by members of the staff of this laboratory for the purpose of determining the relationship, if any, of diagnostic lumbar puncture, in the presence of a septicemia, to the subsequent occurrence of meningitis. To this end, blood cultures were taken at the time of the lumbar puncture and the cases were followed subsequently with reference to the development of meningitis. In a number of cases in which a septicemia was present, the first diagnostic lumbar puncture yielded a clear and normal cerebrospinal fluid in which no organisms could be demonstrated; later fluids from these cases were turbid and contained the organism isolated from the blood culture. Two cases of pneumococcus septicemia developed a meningitis, subsequent to diagnostic lumbar punctures yielding normal fluids. In one of meningococcic septicemia, a negative spinal fluid at the time when the blood culture was positive, was obtained; the presence of an early meningitis was observed at autopsy. The case suggested a possible relationship between the release of cerebrospinal fluid during the septicemia and the subsequent meningitis. Three other patients with meningococcic septicemia were observed; lumbar puncture in all three yielded initial negative

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fluids. Within 48 hours two of the three had developed a definite meningitis. Interpreted from the standpoint of the experimental work in this laboratory, the relationship of the withdrawal of cerebrospinal fluid during a septicemia to the development of a meningitis was indicated.

To prevent the possible accidental production of a meningitis as the result of diagnostic lumbar puncture, it was recommended that careful consideration be given the bacteriological study of the blood before such punctures were attempted; and that in acute diseases, in the absence of definite signs of irritation of the central nervous system, lumbar puncture should be avoided unless it was first conclusively shown that the blood stream was free of infection.

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CHAPTER VIII

MOTOR DISTURBANCES IN PERIPHERAL NERVE LESIONS [a]

One of the functions of a peripheral nerve is the transmission of motor impulses. When a peripheral nerve is injured or severed its function is diminished or destroyed, thus resulting in a loss of motion. If the loss of motion is complete, it is defined as paralysis, if incomplete as paresis. The state of the function of motion is determined by an examination of a muscle at the moment of voluntary or willed movement. Inasmuch as many muscles are deep-seated and others seem to contract when synergistic muscles are shortened, it is impossible, in many instances, to determine paralysis by an examination of the muscle itself; consequently, the preservation of the function of muscles is largely determined by the examination of movement of segments about the joints.

Loss of motion may be the result of conditions other than paralysis of a muscle or muscles. Among these causes may be included local shock, pain, swelling, fractures, dislocations, adhesions, or ankylosis of joints, contracture of opposing uninjured muscles, spasm, sclerosed fibrous tissue, as in ischemic paralysis, tendon and muscle section or loss, and hysteria.

EXAMINATION OF MOTOR FUNCTION

POSTURE

Loss of function of any peripheral nerve produces a position and deformity which is characteristic, such as wrist-drop of musculospiral nerve paralysis, frequently associated with a "tumor of the wrist" due to the distention of the ligaments of the wrist, producing a protrusion of the proximal metacarpal bone. Other deformities include the talipes equinovarus or foot-drop of external popliteal nerve paralysis, the talipes equinus of sciatic nerve paralysis, the ape hand of ulnar and median nerve paralysis, the characteristic position of the thumb in a plane with the palm, in median nerve paralysis, the sagging shoulder of a spinal accessory nerve paralysis, the winged scapula of a long thoracic nerve paralysis.

RANGE OF MOVEMENT

The degree of motility of segments about a joint should be determined by examination of both active and passive motion. In examining for passive motility due consideration must be given to the pain elicited. The range of movement may be determined by a goniometer and measured in degrees of a circle, or by tracings obtained from molds made with a flexible lead tape.

[a] The subject matter treated herein is general in nature; that is to say, much of it was known prior to the World War; however, its inclusion is believed to be essential to a clear understanding of how nerve lesions were treated during the period of the war.—Ed.

first obtaining a tracing of the movements of the segment in one direction (flexion) then in the other direction (extension).

It is important to note the position of segments of joints adjacent to the ones being examined, for example, in musculospiral paralysis with wrist-drop there may be some interphalangeal joint fibrosis. If the range of flexion of the fingers be obtained with the wrist "dropped" it will be far less than with the wrist in a position between extension and flexion. Similarly in median and ulnar nerve paralysis the range of extension of the finger will be less with the wrist extended than when the wrist is flexed. In popliteal nerve paralysis the dorsal flexion of the foot will be less with the leg extended than when it is flexed.

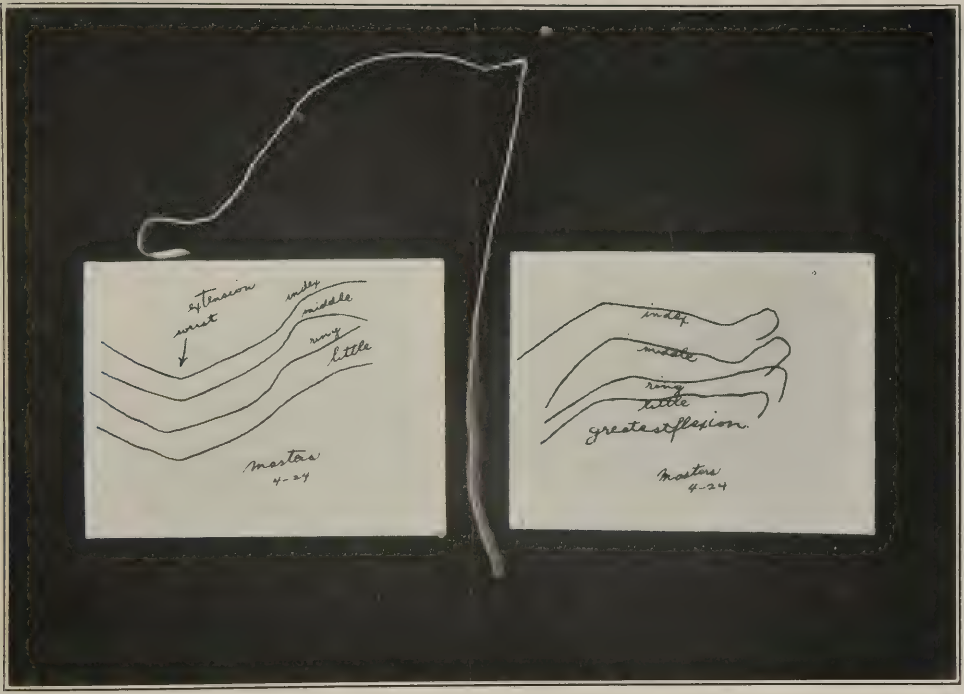

Fig. 80.—Lead tape and tracings

ACTIVE MOTION

Because of the many factors entering into the movement of segments about the joints, but particularly because of the frequency with which more than one muscle may produce similar movements about the segments of the joints, the necessity for great care in the analysis of all muscle movements is stressed.

The segments about the joints in the body may normally be moved in certain directions to certain degrees, flexion, extension, abduction, adduction, rotation, circumduction, etc. The failure of such movements indicates a loss of function which with certain precautions may be attributed to the motor paralysis.

Having eliminated such causes as pain, swelling, contracture, spasm, fibrosis, ankylosis of joint, fracture, etc., one begins to study the loss of function by observation of range of motility in various directions. Here certain precautions are necessary. Each joint must be studied separately. The part of the extremity proximal to the joint tested should be passively immobilized; for example, in testing for extension of the wrist, the forearm should be immobilized. Just as in examining for passive motility so here the muscles moving the segment should be placed in a position which is neutral, so that their function can best be motivated. In a musculospiral paralysis, although the flexors of the fingers are uninjured, the degree and force of motility is diminished unless the hand is passively extended on the wrist.

The influence of gravity must be properly evaluated and its forces nullified by proper position. Paretic muscles may be capable of contraction and be too enfeebled to move a part or whole of any extremity against gravity. A deltoid muscle may be enfeebled to such a degree that abduction of the arm to a right angle is impossible when the patient is standing, but with the patient in a supine position, abduction of the arm may be possible. At times under this condition it is advisable further to facilitate movement and diminish the force of gravity by placing the paretic extremity on a board which has been powdered with talc.

In a musculospiral lesion, extension at the wrist may be impossible with the forearm unsupported and in a pronated position, yet feeble extension may be produced with the forearm in a position midway between pronation and supination and supported on a powdered board. Similarly flexion of the forearm may be impossible against gravity, but possible if the upper extremity is supported in a position of abduction at a right angle. Extension of a paretic quadriceps femoris may be impossible in an erect position with the thigh flexed and quite possible when the lower extremity is supported on its inner or outer surface while the patient lies on his side. Such precautions must be taken as well in examining the hamstrings, the dorsal and plantar flexors of the feet, in short, of all the muscles of the body.

At times the force of gravity works in the opposite direction and, as will be pointed out under supplementary movements, it often produces a movement which is misinterpreted as muscle function. When the triceps is paralyzed, if the arm be abducted, the forearm flexed and then externally rotated, gravity may produce extension at the elbow. Similarly when the quadriceps femoris is paralyzed and the thighs passively flexed on the abdomen and the legs on the thigh while the patient is in a supine position, gravity may extend the leg.

At times a muscle may be so enfeebled that it can not change the position of the segments about a joint but its contraction can be ascertained by palpation. Frequently such examination leads to erroneous conclusions, as in ulnar nerve paralysis the tendon of the flexor carpi ulnaris may seem to contract when the wrist is flexed by the flexor carpi radialis and palmaris longus.

Sometimes if the paretic segment be passively moved in the direction of the action of the paretic muscle the patient may actively increase this movement. For example, in an external popliteal nerve paresis, if the foot be

passively dorsi-flexed to a degree, the patient may then be able to actively increase the degree of dorsi-flexion of the foot.

Frequently, although the patient may not be able to produce a movement of a segment in a certain position, he may be able to retain this position when it is passively produced, as in a paresis of the extensors of the wrist, when the wrist is passively extended, he may for a brief interval hold it in that position.

The degree of motor deficiency may be measured relatively by the observation of the degree of capability of producing change in position of segment in (*a*) neutral position, (*b*) against gravity, and (*c*) against interposed resistance. In estimating the amount of interposed resistance one may compute it in degrees of one's own strength or as compared with the uninjured corre-

Fig. 81.—Spring scales dynamometer

sponding segment of the patient. In a paresis of the extensors of the wrist, one may compare the strength of the paretic to the normal side by resisting with one's own hands the extension at the wrist. The degree of motor deficiency may then be described as paralyzed, very weak, moderately weak, weak, or moderately strong, and so recorded.

The necessity for accuracy in the examination of motor function can not be overemphasized. Careful measurements and precise records are necessary not only for the purpose of diagnosis and prognosis, but also for the determination of the progress of a case. Accurate measurement of motor function is possible only by a dynamometric examination.

A simple and accurate method may be employed by the interposition of a spring scale between the examiner's hand and a segment to be examined. One

may employ several such scales, some measuring to 500 grams and others as high as 50 pounds. To determine the strength of flexion of the distal phalanx of the thumb the hook of the scale is fastened to the distal phalanx and, holding the scale in one hand, the remaining portion of the thumb is fixed or immobilized with the other hand. The patient is then requested to flex the thumb and the degree of motor function is read in terms of grams or pounds. It is essential that influence of movement of adjacent segments be avoided by passive fixation.

When dealing with more complicated movements, such as pronation, or supination, or rotation, a flat piece of wood at one end of which a hole has been drilled may be employed. The hook of the scale is inserted into the hole and the patient grasps the flat piece of wood and, turning it either by pronation or

FIG. 82.—Measuring pronation by spring scales

supination, the results may be read upon the scale. At times it may be necessary to bind the hook of the scale or the piece of wood to a segment about the joint being examined.

The results so obtained may be recorded opposite the name of muscles supposed to move the segment in the direction measured, or, and this is far more accurate, upon a diagrammatic representation of the segment. For example, in examining the movements of the hand and fingers, each result is noted upon the palm or dorsal surface of the part of the hand recorded. Schematic representation of abduction of the fingers, flexion of the proximal phalanges, adduction, opposition and short abduction of the thumb, may be denoted as in the following illustration (fig. 83).

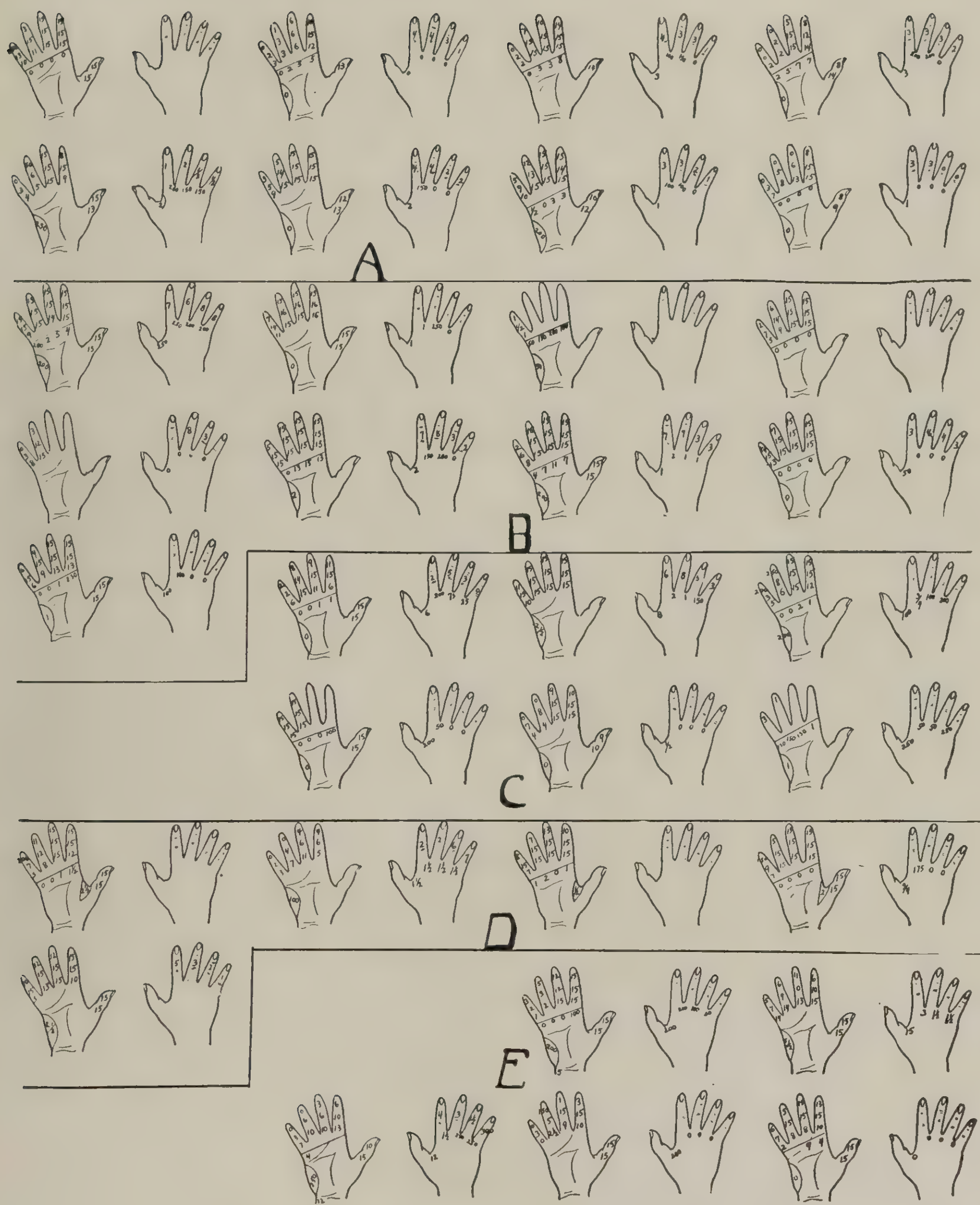

FIG. 83.—Ulnar nerve lesions: A, Anatomical section verified at operation, complete sensory loss; B, severe lesion not anatomical section, complete sensory loss; C, compression of ulnar nerve, verified at operation, partial sensory loss; D, partial and recovering lesion not verified by operation, complete sensory loss; E, cases similar to D with some sensory regeneration. Only four cases showed sensory regeneration in the absence of motor recovery

In lesions of the ulnar and median nerve this type of examination and recording has led to the observation of many phenomena of great diagnostic and prognostic value which have not heretofore been described. These are dealt with under injuries of the several nerves.

SUPPLEMENTARY MUSCLE MOVEMENT

Supplementary muscle movement, supplementary motility, or supplementary motion or trick movement, is frequently responsible for misinterpretations in the examination of cases of peripheral nerve lesions.

The preservation of certain movements, the loss of which is supposed to follow particular nerve lesions, has been observed for many years. Sherren [1] called attention to the fact that Swan,[2] in 1824, was astonished at how much a rabbit could move its leg after experimental section of the sciatic nerve. Later Letievant [3] studied this phenomenon and termed it supplementary motility. Since that time numerous investigators have observed its presence in peripheral nerve lesions, notably Duchenne [4] and Beevor,[5] to whom may be credited much of the present knowledge of these movements. Head and Sherren,[6] Claude,[7] and Athanassio-Benisty [8] are among the recent observers who noted its presence. American workers, Coleman,[9] Woods,[10] and Pollock,[11] among others, have been particularly interested in these movements and have contributed considerable information as to their occurrence.

These movements may be caused by a number of factors, among which may be included the anastomotic supply of muscles from adjacent nerves, and one must recall the not uncommon existence of an atypical nerve supply—total supply of the flexor brevis pollicis by the ulnar nerve, and the supply of the first dorsal interosseous by the median. Supplementary muscle movements may likewise be produced by muscles other than for primary movements—the flexion of the wrist which is produced by contraction of the abductor longus pollicis and the extensor ossis metacarpi pollicis; by movement occurring as the result of mechanical factors producing a change of direction of leverage by the shortening and lengthening of tendons and muscles passing over several joints—in a lesion of the musculospiral nerve with paralysis of the extensors of the wrist, when the wrist-drop does not exceed an angle of 120°, complete flexion of the fingers produces extension at the wrist; by slight movement resulting from the recoil of elastic tissue following a movement in a direction opposite to the one desired—in median nerve paralysis flexion of the distal phalanx of the thumb may be imitated by the recoil occurring following strong extension of the distal phalanx of the thumb; by utilizing the force of gravity—in paralysis of the median nerve pronation may be produced first by stretching the long wrist and finger extensors and then the forearm resting on the knee the remaining portion of pronation is produced by allowing the force of gravity to carry the forearm through the subsequent action.

RECOVERY OF VOLUNTARY MOTILITY

The order in which movement is restored to muscles paralyzed as the result of peripheral nerve lesions has a sufficient constancy to attribute to each nerve a clinical individuality.[12] Generally speaking, with severe lesions of

the nerve, a certain degree of muscular tonicity returns before any reappearance of voluntary motion. At first, voluntary movements are awkward and uncertain and frequently the reaction time of a movement is considerably lengthened. One must bear in mind what has been called by André-Thomas [13] "an error in the switching" of the motor fibers which have not taken the proper direction and have not encountered each time the sheaths intended for their reception, as when a patient suffering from an injury to the musculospiral nerve wishes to extend his wrist the supinator longus contracts powerfully and often in excess of the radial muscle.

At times it has been noted that preceding the ability to produce voluntary motion the patient experiences a feeling of being able to produce such motion when he wills it. Thus, in a musculospiral lesion before recovery has taken place, the patient may not have been able to sense the feeling of extension, whereas when recovery is taking place he begins to feel the sense of extending the wrist, although such extension may not be produced.

FURTHER CONSIDERATION OF CERTAIN FACTORS PRODUCING DEFECT IN MOTION

Some of the factors producing defect in motion deserve additional description.

SHOCK

Loss of motion following injuries of war may occur as the result of local shock and not as a result of direct injury to the peripheral nerve. Immediately following the reception of a gunshot wound there may be a complete paralysis of an extremity. This paralysis more or less rapidly disappears and if a peripheral nerve is injured, may leave paralysis of the muscle supplied by that nerve. Return of motor function occurs in from a few hours to a number of days, depending upon the amount of shock and the degree of injury of the soft parts and blood vessels. This loss of motion is far more common in injuries which are the result of shrapnel and high-explosive shells than of bullets. It is a constant accompaniment of wounds associated with fractures of long bones. It is not necessarily an accompaniment of loss of consciousness or surgical shock.

This loss of motion rarely is accompanied by loss of sensation and it is notable that, even when a nerve is injured by local concussion or at times by contusion, frequently motor function is lost whereas sensation is preserved. S. Weir Mitchell [14] observed this during the Civil War.

JOINT HANGES

S. Weir Mitchell called attention likewise to the common affection of joints in lesions of the peripheral nerves and, as in the Civil War so in the World War, these changes produced immobility at times of greater importance than paralysis of muscles themselves. These joint changes may be of a number of varieties and their causes not easily determined. Of the known causes one may enumerate fractures in the joints, dislocations, suppuration of joints, prolonged suppuration of nearby parts, prolonged immobilization, ischemic

contractures resulting in retraction of muscle tendons, and certain nervous lesions the character of which is unknown.

Although it is supposed generally that prolonged immobilization is the primary cause of most of the joint changes there are many cases in which this is not so. Occasionally one may see an early arthritic involvement consisting of a painful swelling of the joint, which differs from the early inflammatory swelling of the wound itself. This may last for weeks, and be followed by partial ankylosis. At other times a gradual retraction of muscular tendons and hardening of a joint capsule occurs, sometimes associated with prolonged and particularly improper immobilization, at times associated with prolonged suppuration. Very frequently one sees changes in painful and partial nerve lesions, characteristically present in painful lesions of the internal popliteal and median nerves, perhaps as a part of the picture of causalgia. These partial and painful lesions must consist of more than only a direct injury of part of a nerve because there is no more reason why an injury to a part of a nerve should be followed by joint changes or ankylosis than an injury of a whole nerve where, in the absence of a suppurative lesion, no immobilization or joint changes may be present. They are probably associated with a definite low-grade infection which follows the lymphatics of the nerve to the joint.

Injuries of certain nerves produce changes in certain joints peculiar to themselves. For example, injuries to the musculospiral nerves in the middle of the arm are associated with ankylosis of the elbow. When this ankylosis occurs early it is associated with a spasm of the biceps, when late it is the result of prolonged suppuration or fracture of the humerus. In painful lesions of the median nerve the joint changes are notable, widespread, and of severe character; the interphalangeal and metacarpophalangeal joints of all the fingers are affected. At times a partial ankylosis of the metacarpophalangeal joints of the thumb occurs wherein only abduction and adduction are possible, and as a result attempts at extension produce abduction at right angles to the plane of the palm. The wrist joint and at times the elbow joint may be involved. What is true of the painful partial lesions of the median nerve is likewise true of the ulnar to a far lesser degree. The interphalangeal joints of the foot may be involved in a partial painful lesion of the internal popliteal and limitation of abduction of the foot is often seen in external popliteal lesions.

Shortening of opposing muscles is not so frequently observed since the necessity of proper splinting has been recognized. Occasionally it occurs and offers retardation to recovery of function. Such shortening is seen commonly when deformities occur as the consequence of the force of gravity in addition to overaction of unopposed muscles, as in musculospiral paralysis affecting the flexors of the wrist, in paralysis of the external popliteal affecting the tendo Achillis, and to a lesser degree in circumflex nerve paralysis, affecting the pectoral muscles. Such shortening may occur even when gravity does not contribute to the deformity, as in overaction of the extensor communis digitorum in ulnar nerve paralysis, shortening of the abductor pollicis and the extensor ossis metacarpi pollicis in median nerve paralysis, of the lumbricales in radial nerve paralysis, of the extensor communis digitorum in internal popliteal nerve paralysis, of the tibialis posticus in external popliteal nerve paralysis.

MUSCLE SHORTENING RESULTING FROM SPASM

Muscle shortening may at times result from a different cause, namely, spasm. This condition is usually observed in partial lesions of the peripheral nerves; in muscles the nerve supply of which may not have been primarily injured. These partial lesions are the result of some irritative agent acting, perhaps, reflexly. Often they are associated with some vascular lesion. At times they occur as an accompaniment of a painful lesion of an adjacent joint or bursa—in arthritis of the shoulder, or in subacromial bursitis, a spasm of the pectoralis major frequently is observed. Such spasms are to be clearly differentiated from the so-called physiopathic reflex nervous disturbances which occur without any lesion of a peripheral nerve and from lesions at a distance from the site of loss of function. Similarly, they must be differentiated from the fibrous shortening of ischemic or Volkmann's paralysis.

ISCHEMIC PARALYSIS

In addition to the compression produced by bony callus, that which is produced by sclerosing fibrous tissue must be considered. In such cases there may be no symptoms suggestive of nerve injury immediately following the trauma, but a few weeks later particularly after the removal of a dressing such as a splint or a plaster-of-Paris cast, symptoms of compression manifesting themselves by partial or complete paralysis will be found. In this group the largest number of cases consists of those due to the formation of sclerosing fibrous tissue. This sclerosing results from the organization of diffused blood or of the products of inflammation. The symptoms, particularly the motor symptoms, are frequently confusing in so far as the diagnosis of a possible peripheral nerve injury is concerned. Characteristically, however, such a lesion is never limited to the distribution of the muscular supply of any one or more peripheral nerves; all muscles in an extremity may be involved to a greater or lesser degree. The sensory changes are not definite and when they occur they too are not limited to the anatomical sensory distribution of the peripheral nerves or a combination of such nerves.

The electrical reactions do not show the changes consistent with a pure peripheral-nerve lesion. One may find that certain parts of muscles supplied by an individual nerve may react to faradism whereas other parts do not. In general, it may be found that, commensurate with the degree of fibrosis, the muscles have a disappearance of both faradic and galvanic response. Interphalangeal fibrosis, with partial or complete ankylosis, is very common. Coldness of the extremity and the cyanosis are characteristic signs.

TONE

When a peripheral nerve is severed the spinal reflex is interrupted in the motor arc and loss of tone results. If one could measure loss of tone accurately, and if the degree of hypotonicity were an accurate indication of the severity of peripheral nerve lesions, it would be important that this function be carefully examined. Unfortunately, loss of tone occurs in partial lesions as well as in complete lesions of peripheral nerves. It is measurable only in the

early stages following a wound to a peripheral nerve, inasmuch as later it may be complicated by other factors such as swelling, fibrosis, and contracture, as the result of changes consequent to fracture, joint changes, suppuration, and vascular changes. Frequently, after the secondary changes have disappeared, a fibrosis or hardening results which prevents an accurate determination of the tone of an extremity. The position of an extremity is not always an indication of the hypotonicity of the muscles, inasmuch as secondary shortening may prevent wrist-drop or foot-drop. Tone may be measured by some objective method, as the employment of a tonometer which may be rather simply made, as shown in Figure 84.

FIG. 84.—Tonometer

When measured in this manner it is found that soon after an injury of a peripheral nerve, in the absence of any changes, such as swelling and inflammation, there is a marked hypotonia which may be measured in the amount of millimeters of mercury necessary to push the plunger a certain distance into a muscle mass. Whereas, in a normal muscle a pressure of 160 to 180 millimeters of mercury may be required, in a paralyzed muscle a pressure of but 40 to 60 millimeters of mercury is sufficient to plunge the indicator 10 millimeters into the mass. Some time after injury this type of examination proved to be quite useless, because the subsequent atrophy frequently vitiated the result

of the examination. Although one may find frequent references to the return of tone as an indication of the return of function of a muscle, it has been found that the secondary changes prevent the observation of the return of this function. When observed, of course, it is a valuable sign, and if in a given case of musculospiral paralysis with a certain degree of wrist-drop as the result of hypotonicity the wrist is seen to assume an attitude in which it drops to a lesser degree, this may be accepted as a hopeful sign in the absence of secondary shortening.

ATROPHY

What has been said of tone is true also of atrophy. For some time it has been accepted that when a peripheral nerve is severed trophic disturbances occur in the muscles and these disturbances are followed by atrophy of the affected muscles. It has been supposed that this atrophy is commensurate with the degree of injury of the peripheral nerve. Although this is true, one is unable to measure the degree of atrophy so accurately as to make it a valuable sign in differentiating complete from incomplete lesions, and extensive atrophy of a paralyzed muscle may be interpreted, with a number of reservations, as meaning a severe lesion. Ulnar nerve lesions, as a rule, show extensive atrophy whether they are severe or not. As a sign, atrophy is of service in denoting the severity of a lesion only when seen soon after injury; the amount of atrophy observed some months after an injury is not commensurate with the severity of the lesion. Painful lesions of the median nerve and of the ulnar nerve are very frequently associated with rapid and marked atrophy. When observed some months after injury absence of demonstrable atrophy is not an indication of a reparable lesion. Frequently replacement of muscle mass by other tissues is responsible for the seeming lack of atrophy, and no method of examination permits us to determine how much atrophy has been present. Inasmuch as peripheral nerve lesions are associated with destruction of other tissues such as fracture and lacerations of muscles and soft parts with blood vessel lesions, it is apparent that seeming atrophy of long muscles or muscle masses may frequently be the result of disuse and factors other than trophic changes in the nerve supplying that muscle.

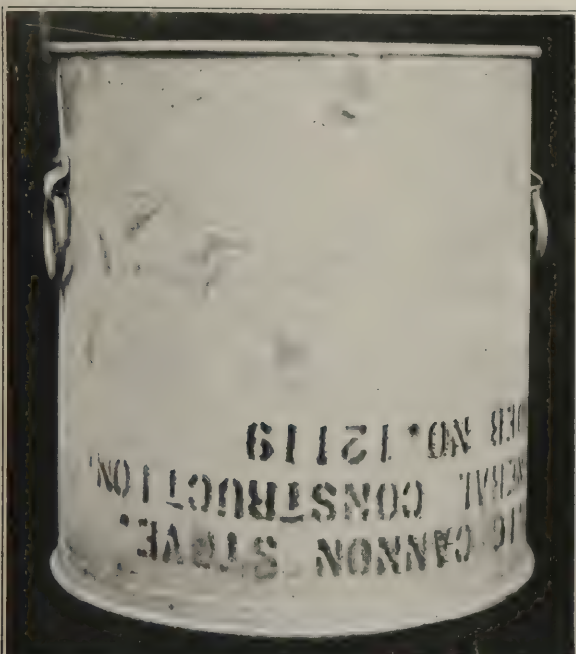

Fig. 85.—Can with spout for measuring volume of extremity by water displacement

If, for example, one measures the amount of water displaced by an atrophied extremity as compared with the amount displaced by the opposite normal one, some interesting facts are discovered (fig. 85). As compared with the unaffected extremity, the affected one shows in an irrecoverable ulnar nerve lesion an atrophy of 4.5 per cent of the total mass; in recovering lesions 4.2 per cent; in radial nerve lesions there is an atrophy of 4.3 per cent in recovering lesions, 5 per cent irrecoverable ones. In lesions of the median nerve those recovering showed 11.2 per cent and irrecoverable 50 per cent atrophy; in sciatic nerve lesions recovering lesions showed 9.7 per cent and those irrecoverable 10 per cent; the external popliteal showed in the recovering lesions 6 per cent and in the irrecoverable 7.2 per cent.

Although the percentage of loss of muscle mass was slightly greater in the severe irrecoverable lesions, the difference was not sufficient to be of diagnostic or prognostic value. In addition to this, some irrecoverable sciatic nerve lesions showed but 1 per cent loss when a recovering one showed a 17 per cent loss. In a recovering external popliteal nerve lesion 16 per cent loss was found and in an irrecoverable one only 1 per cent loss. This immediately indicates that the demonstration of atrophy is not an accurate guide to the severity of the lesion, and the absence of atrophy does not indicate a recoverable one. Although some of the discrepancies are probably due to the replacement of muscle fibers by other tissues, it would seem in some instances that those cases wherein exercise and massage, electrical stimulation, and passive movement of the extremity were given that the degree of atrophy seemed less.

Though ulnar nerve lesions show predominantly the greatest degree of atrophy rapidly occurring, radial nerve lesions show the least atrophy.

Graphic methods of recording signs and symptoms in many instances have a greater value than descriptive methods. Frequently it is impossible to have photographic records of the hands and feet in cases of peripheral nerve lesions; under this condition it is found serviceable to record the contour of the palm and sole by making impressions of the hand and foot. The degree of atrophy and resulting deformity of the hand and foot indicate clearly the type of peripheral-nerve lesions with which we are dealing. Not only is the position of the hand determined but the atrophy and the contracture of the muscles are shown as well. Only five of the peripheral nerves showed distinctive changes in a sufficiently large percentage to make it profitable to study lesions by this method. These nerves are the ulnar, median, radial, internal popliteal, and sciatic. The picture produced by a combined lesion of the ulnar and median is likewise distinctive. The imprint of the hand in the case of a lesion of the ulnar nerve shows the following characteristics: The clawing of the inner two fingers is well demonstrated by the absence from the imprint of any part of these fingers except the tip. The hypothenar muscles are seen to be atrophied by the presence of a notch on what normally consists of a rounded contour made by these muscles (fig. 86).

Between the mounds of the ring and middle finger is seen another notch, and when the atrophy is very severe a notch appears between the ring and little fingers as well (fig. 86–c). The fingers can not be spread apart, and the first phalanx of the thumb is in a position of extension. The atrophy of the ad-

FIG. 86.—Imprint in a case of ulnar nerve lesion: *a*, Affected; *b*, affected; *c*, affected; *d*, normal; *e*, affected; *f*, affected. A, Notch indicating atrophy of hypothenar muscle; B, notch between the mounds of ring and middle finger indicating atrophy; C, break in line along the radial border of the base of the index finger indicating atrophy of the adductor pollicis

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ductor pollicis is seen by a break in the line along the radial border of the base of the index finger (fig. 86–d).

Median nerve lesions show very clearly the disturbance of whorl formation on the tips of the index and middle finger (fig. 87–a). When severe clawing is present in these two fingers, it is marked by the imprint of the very tip, frequently including the nail. The atrophy of the thenar eminence is usually well marked, and is shown by the prominence of the base of the thumb and a considerable notch in the normally rounded contour of the radial border of the thenar eminence (fig. 87–b). The distal phalanx of the thumb is in extension. When severe clawing is present, it is made evident by the absence of any imprint of the central portion of the palm. Not only is the atrophy of the thenar eminence noted by the notches proximal to the base of the thumb, but also in many instances loss of tissue is demonstated along the radial border of the first phalanx of the thumb (fig. 87–b). Failure of desquamation and the presence of many new lines is demonstrated over the thenar eminence (fig. 87–c).

Radial nerve lesions are characterized by the cramped appearance of the finger which results from inability to place the palm flatly on the paper because of the flexed position. The most characteristic feature of this imprint is the position of the thumb, which is adducted, the distal phalanx falling within or on the border of the outline of the index finger. The thumb is rotated about its axis inwardly so that the radial border of the distal phalanx is straight and not rounded. The distal phalanx of the thumb is usually flexed. Absence of the signs of atrophy in the thenar and hypothenar eminences is an additional feature of this form of lesion.

In combined lesions of the ulnar and median nerve signs of atrophy of both the thenar and hypothenar eminences are demonstrable by these notches found along their borders (fig. 89–a). Clawing is present in all four fingers; the mounds are often separated (fig. 89–b). The center of the palm shows a larger area in which no imprint is seen. When, in addition to partial lesions of the ulnar and median, the radial nerve is involved, the thumb shows at times the same rotation as was observed in the radial lesions. Frequently in lesions of the external popliteal nerve there is a flattening of the toes, so that the plantar surface of the entire length of the toe will produce an imprint. Lesions of the sciatic nerve show, in addition, a slight pes cavus, and in some cases a clawing of the toes, indicated by the absence of their imprint on the paper.

MUSCULOSPIRAL NERVE

The position of the hand in musculospiral paralysis is characterized by a very marked drop of the hand and fingers; the wrist and first phalanges are flexed; the thumb is abducted and falls within the line of the outer border of the index finger (fig. 90).

The best method of testing the function of the triceps is to allow the patient's arm to hang over the back of a chair, the arm being horizontal, the forearm hanging loosely at right angles to it. The patient is asked to straighten his arm. The muscle may then be both inspected and palpated during the attempt. Care must be exercised not to misinterpret that extension of the

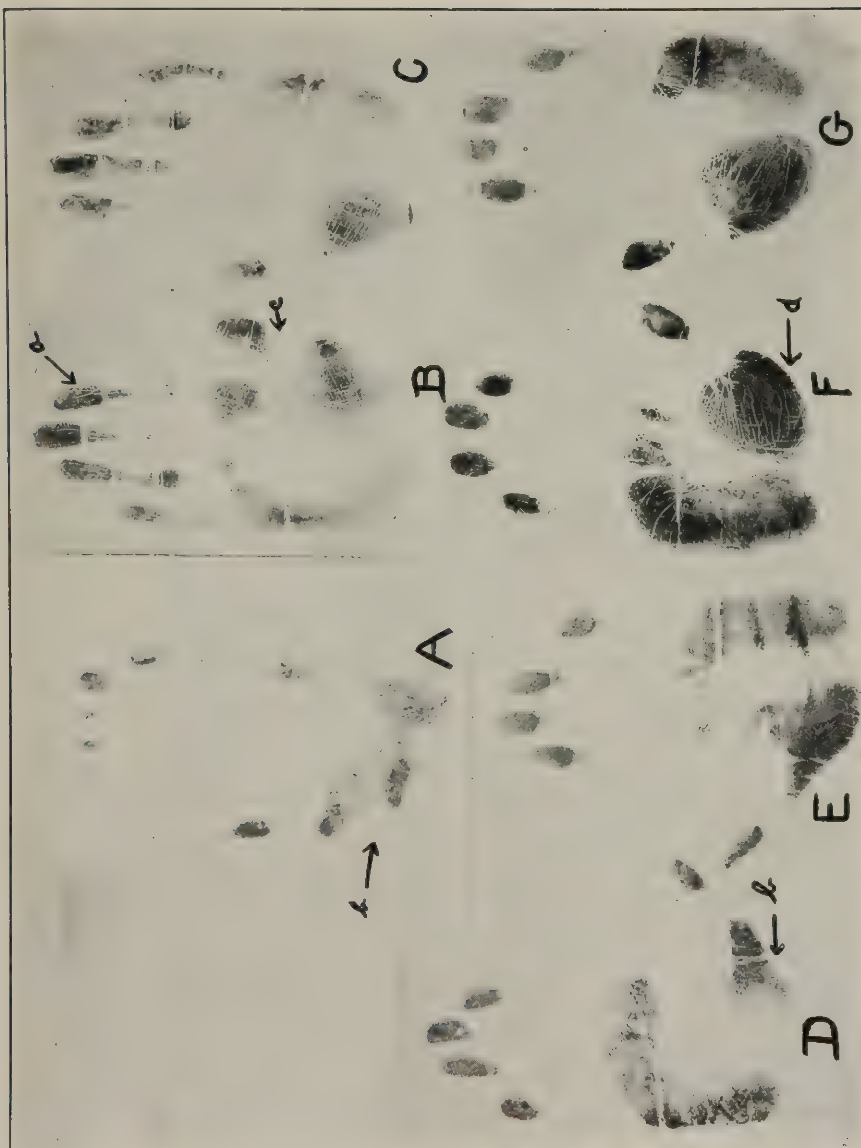

FIG. 87.—Imprint in case of median nerve lesion: *a*, Affected; *b*, affected; *c*, normal; *d*, affected; *e*, normal; *f*, affected; *g*, normal. A, Disturbance of whorl formation at tips of index and middle fingers; B, prominence of base of thumb and notch in contour of radial border of thenar eminence indicating atrophy of thenar eminence; C, loss of tissue along radial border of first phalanx of thumb; D, failure of desquamation and presence of many new lines over thenar eminence

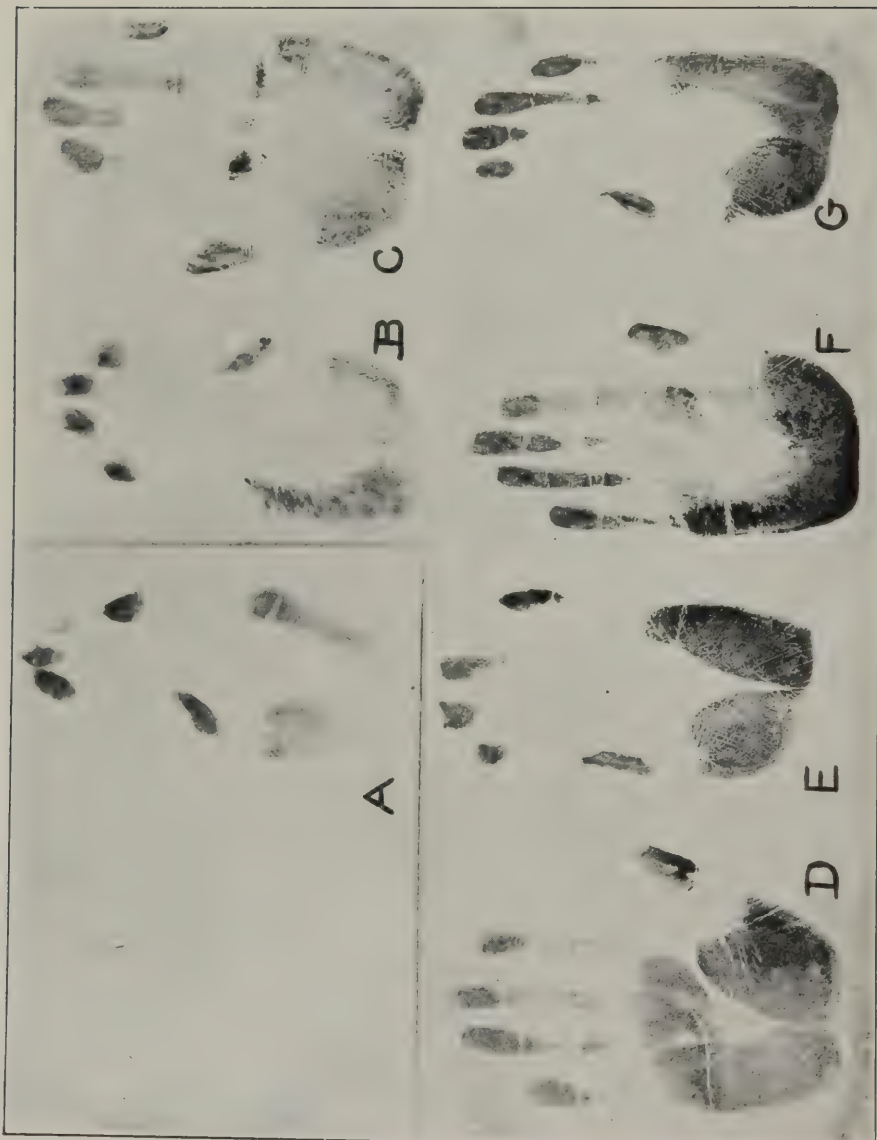

Fig. 88.—Imprint in case of radial nerve lesion: A, Affected; B, affected; C, normal; D, normal; E, affected, paralyzed abductor pollicis; F, normal; G, affected

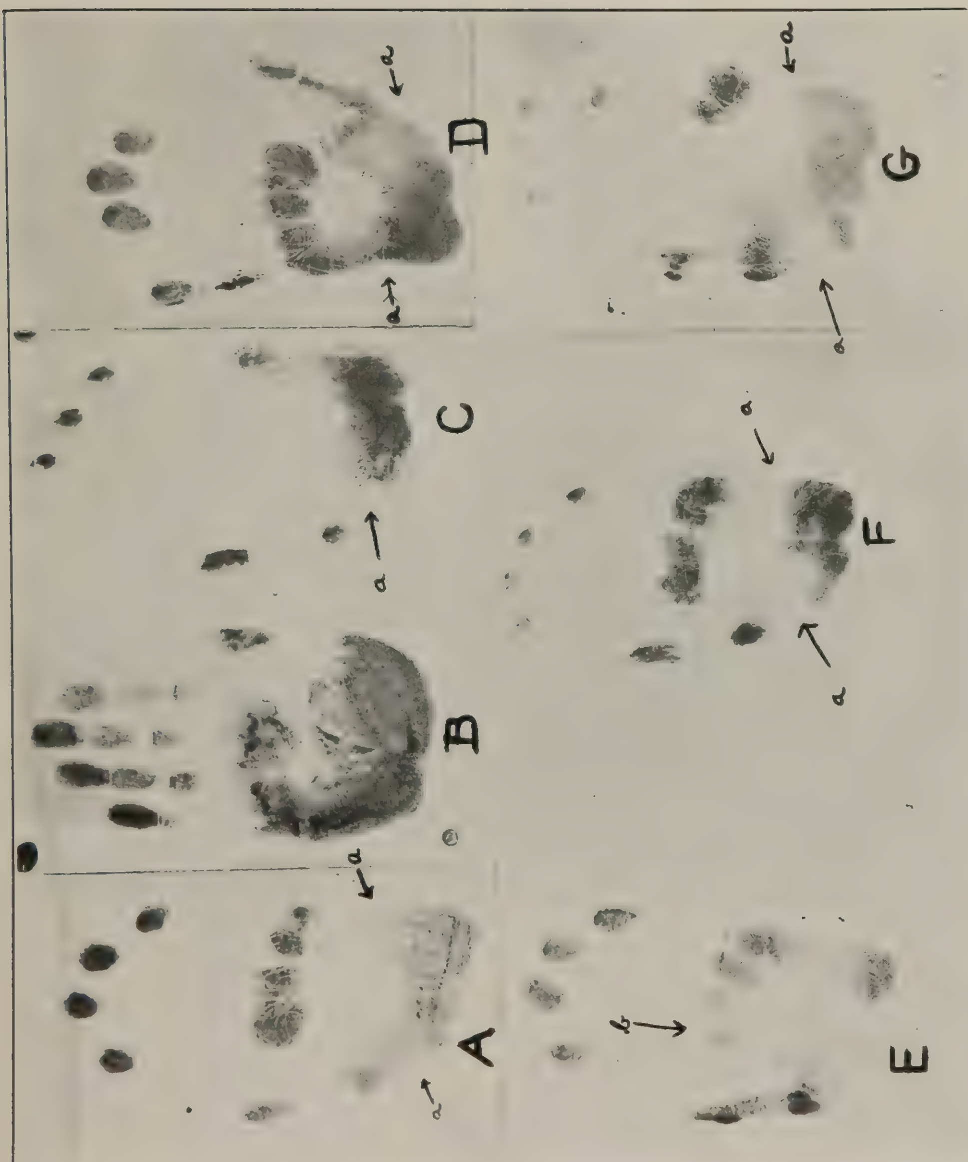

FIG. 89.—Imprint in combined lesions of ulnar and median nerves: *a*. Atrophy of thenar and hypothenare minences; *b*, separation of mounds

forearm which occurs from a flexed position as the result of gravity controlled by the flexors. For this reason it is important to have the patient raise his elbow high enough so that it becomes impossible for him to extend the bended forearm by reason of the weight alone. Another way to test the paralysis of the triceps is to extend the elbow, then to ask the patient to resist any attempt to flex the forearm on the arm. Because the long head of the triceps receives its motor supply immediately after the nerve leaves the tendon of the teres major, complete loss of extension of the forearm is infrequent in musculospiral paralysis.

The supinator longus is brought into action when flexion of the forearm is attempted with the forearm semipronated. With the extremity in this position the patient is asked to resist extension at the elbow, under which condition an unparalyzed supinator longus will stand out prominently. Contrary to generally accepted statements that the biceps can not aid in supination

Fig. 90.—Musculospiral palsy

unless the elbow is partly flexed, at times the biceps supinates the forearm even when it is completely extended.

Weakness of the extensors of the wrist is observed when the patient attempts to raise the hand against the action of gravity. In eliciting this sign care should be taken to keep the elbow and forearm of the patient motionless and resting on a table with the hand loosely suspended and pronated. When the extensors of the wrist are paralyzed no contraction is felt during the attempt at extension; on the contrary, there is energetic contraction of the flexors of the hands and fingers. Inversely, an attempt at flexion of the fingers does not produce a synergistic extension at the wrist, and it will be found that the patient can neither close his fist nor flex all the phalanges completely; the third phalanx will flex badly or not at all (fig. 91). To verify lateral movements at the wrist, the possibility of error arising from the movement of the elbow should be elimi-

nated by resting the forearm on a table but the hand should be raised almost to the horizontal instead of being allowed to drop. A certain amount of abduction is possible in paralysis of the extensor through the action of the flexor ulnaris. The abduction, however, is incomplete and faulty, and is accompanied by ulnar deviation.

In a lesion of the musculospiral nerve below the elbow paralysis of the extensors of the fingers may occur without involvement of the extensors of the wrist. Under these conditions the patient can not extend the wrist if, at the same time, he attempts to extend the fingers, but if he flexes the fingers the extension of the wrist may then be accomplished. To explain this we must recall the laws governing the action of the muscles going over several joints.

Beevor[5] states that "when a muscle by passing over two or more joints has two or more different actions, then, if only one of these actions be required,

FIG. 91.—Attempted flexion of fingers in musculospiral palsy

other muscles are brought into the movement whose actions are antagonistic to those of the muscles not required." These synergic muscles place the prime movers (in this instance the extensors of the wrist) in the greatest elongation so as to augment their dynamic power and fix the joint so that the movement may be performed from a secure basis. Still another factor must be considered. Beevor[5] found that if the movement of extending the wrist be performed with the fingers actively and fully extended, the extensors of the fingers have to do all the work themselves and against the contraction of flexors of the wrist until the amount of work is equivalent to 4 or 5 pounds before the extensors of the wrist will join in and help them. In the cited instance of paralysis of the extensors of the fingers with preservation of the extensors of the wrist, the extensors of the fingers can not possibly reach the amount of pull which is necessary before the extensors of the wrist can be made to contract.

Supplementary Motility

In a lesion of the musculospiral nerve, with paralysis of the extensors of the wrist, dorsal flexion of the hand may be produced by the action of muscles not innervated by this nerve, as in the energetic contraction of the flexors of the fingers (fig. 92). This occurs under certain conditions and is noted frequently. When the wrist-drop does not exceed an angle of 120° complete flexion of the fingers produces extension at the wrist. In this condition the extensors of the wrist are shortened by contracture and fibrosis so that the angle between the hand and forearm is such that passive dorsiflexion or dorsal dislocation of the hand occurs. Without this provision the fingers could not be completely closed because of the shortened extensor tendons. The mechanism may be illustrated by using the wrist as a hinge, the hand as the weight, the flexors as the power transmitted through a pulley at the metacarpophalangeal joint to a fixed point at the origin of the extensors of the wrist.

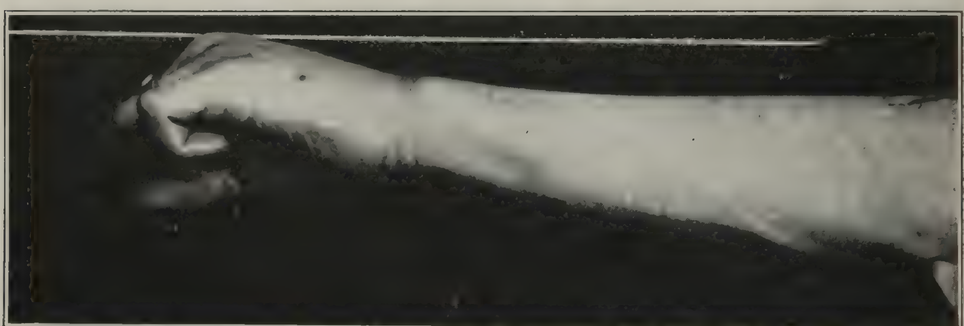

Fig. 92.—Extension of wrist by supplementary movement of flexion of fingers

In some cases strong contraction of the pronator radii teres will produce extension of the hand on the forearm. During this movement the head of the radius is strongly depressed toward the palm, the styloid process at the ulna is pulled dorsally and the hand is deviated to the ulnar side. One may demonstrate readily that the hand can be flexed to a greater degree when the forearm is supinated than pronated, and if flexed to its fullest degree when the forearm is supinated, the hand will be seen to extend when strong pronation is instituted. The extension at the wrist is probably due to two factors: Lengthening of the tensor tendons and muscles; a leverage exerted on the scaphoid by the head of the radius. At times, in addition to the contraction of the pronator, there is seen strong abduction and apposition of the thumb against the proximal phalanx of the index finger. At the same time resistance to this action is made by the contraction of the lumbrical muscle and the hand is extended on the forearm to a notable degree. During this action the middle, ring, and little finger show flexion at the proximal phalanges and extension of the two distal phalanges (fig. 93). Contrary to the opinion of Duchenne [4] and Benisty,[15] the American material when examined showed, in agreement with Beevor [5] and Mackenzie,[16] that for pure lateral movements of the wrist both the extensors and flexors are

necessary. Adduction and abduction of the wrist are superseded by pronation and supination of the forearm in the position of wrist-drop of a musculospiral palsy. If, however, the hand be passively extended to the same plane as that of the forearm, abduction accompanied by flexion of the wrist ensues as the result of contraction of the flexor carpi ulnaris, and occasionally abduction has likewise been observed.

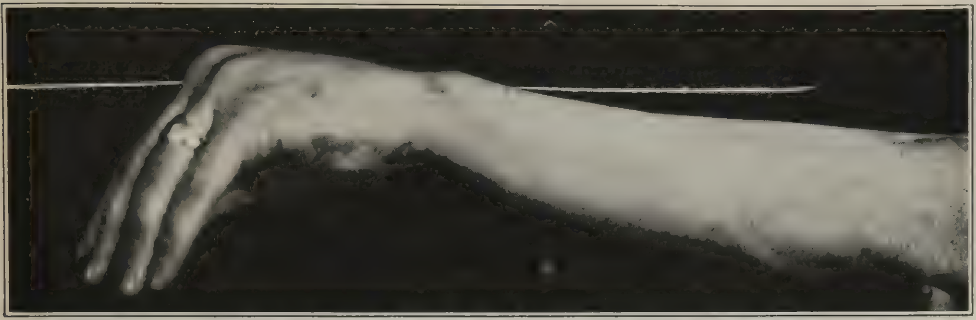

Fig. 93.—Extension of wrist by supplementary movement of contraction of pronator radii teres

The extensors of the fingers extend the first phalanges, and only the first phalanges, of the fingers on the metacarpal bones. To demonstrate the immobility of the first phalanges it is necessary to have the wrist passively semi-extended. Under this condition no extension will take place at the first phalanges. It is possible to tense the proximal phalanges of the fingers by extending the terminal ones through the interossei. At the same time flexion of the proximal phalanges occurs as the result of the unopposed action of the lumbricales. Slight passive extension of the proximal phalanges may be produced by

Fig. 94.—Extension of the distal phalanx of the thumb in musculospiral palsy

flexion of the hand at the wrist. Frequently simulation of extension of the first phalanx of the index finger is accomplished by strong adduction and apposition of the thumb against the first phalanx of the index finger, which is thereby passively lifted dorsally.

The extensor longus pollicis extends the two phalanges of the thumb. In addition to it, however, the abductor and adductor pollicis and flexor brevis

pollicis are prime movers for extension of the distal phalanx of the thumb. Therefore, although never as complete or as strong as when the extensor longus pollicis is spared, the other muscles may produce extension of the distal phalanx of the thumb (fig. 94). Simulation of this movement may be produced by flexion of the distal phalanx of the thumb followed by relaxation. Such a mechanism in frequently observed in slight flexion of the fingers, in ulnar-median lesions and flexion and extension of the toes, in internal and external popliteal lesions, respectively. Abduction of the thumb in the plane of the palm is impossible in musculospiral paralysis and during attempts to abduct the thumb, the tendons of the "anatomical snuffbox" do not stand out in the slightest degree.

Muscle Atrophy

Muscular atrophy is noted two or three months after the injury and may become so marked that it appears as if the skin and subcutaneous tissue were adherent to the posterior aspect of the ulna and radius.

Fig. 95.—Partial lesion of musculospiral nerve

Partial Lesions

It is significant that in lesions in the arm it is usual to find all of the muscles below the innervation to the supinator longus paralyzed, irrespective of the severity of the lesion. However, it may be noted that at times the extensors of the wrist may be paralyzed and those of the fingers unaffected; again, the extensor of the middle finger may be impaired. Occasionally the extensors of the thumb and fingers were involved, whereas the extensors of the wrist were spared (fig. 95). The constancy of certain partial lesions of various nerves has been attributed to the intraneural localization of fibers supplying certain muscles as pointed out by Stoffel,[17] Marie, Meige, Gosset,[18] and Dejerine and Mouzon.[19] However, it may be well to remember that Dustin [20] believes that he has conclusively shown that between each branch of a nerve there was a reassembling of nerve fibers in the form of an intraneural plexus so that a long intraneural pathway does not exist.

Recovery

According to Oppenheim, the muscles recover in direct relation to the length of nerve fibers regenerating. This does not appear to be the case. Benisty [15] states that the order of recovery is nearly always the same. The common extensor is restored only after the radial muscle, the middle, ring, and little fingers begin to extend first, and lastly the index; but sometimes it is the index and middle fingers that first quite recover their movements. The extensors of the thumb and the abductor of the thumb regain their power last of all. From the available observations of the United States Army material a marked difference is seen in that the extensors of the thumb recovered before those of the finger. As to the order of recovery of the extensors of the fingers and thumb, those of the thumb showed some recovery in over 50 per cent of cases but when this did not occur the thumb was almost the last to recover. The extensor of the middle finger was one of the first to recover in over 50 per cent of cases and the index finger was last in one-third of the number of cases. Rarely, return of function was seen in the long abductor of the thumb, and in the extensor of the thumb before that in the extensors of the wrist.

Fig. 96.—Sign of complete recovery of musculospiral nerve

Signs of Recovery

Simultaneous extension of the wrist and all the fingers seems to be the final stage in recovery of voluntary movement. Pitres [21] suggested two tests for determining the completeness of recovery in musculospiral paralysis. The first, placing the arm in an attitude of a man taking an oath, with wrist and fingers extended, the thumb raised and separated from the finger with the tendons of the extensors and the long abductor of the thumb marking out the anatomical snuffbox. Then he is requested to supinate his hand. The second test consists of the patient placing his little finger on the seam of his trousers with his fingers well extended and with the palm of his hand turned to the front.

MEDIAN NERVE

Total Paralysis

When the median nerve has been completely divided or when physiologic function has been lost, the hand inclines slightly to the ulnar side of the arm,

as shown in Figure 97. The index and middle fingers without being completely extended are more extended than normally. There is considerable atrophy of the muscles of the thenar eminence and the thumb is in the plane of the palm

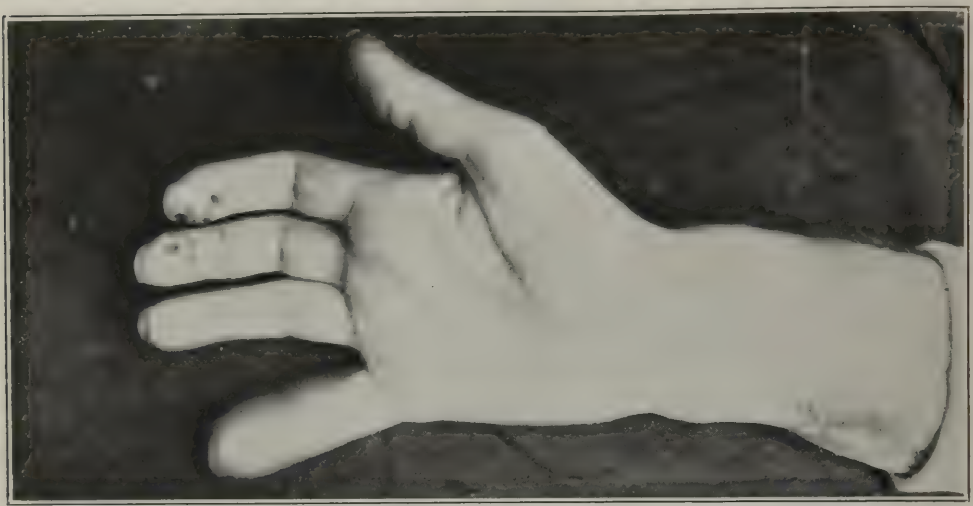

FIG. 97.—Median nerve palsy

producing the so-called "ape hand." Pronation is incomplete and defective. When the forearm is flexed the patient supplements this defect by holding the elbow out. When it is extended he rotates the arm inward, resulting in passive

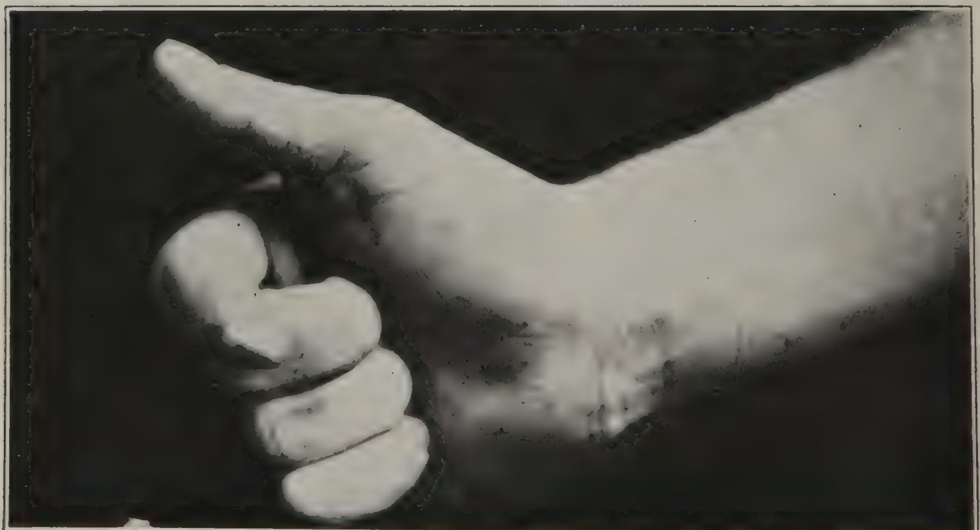

FIG. 98.—Inability to completely close the fist in median palsy

pronation of the hand. Paralysis of the palmar muscle may be determined by palpation of the tendons at the bend of the wrist when flexion at the wrist is opposed. Paralysis of the flexor sublimis and outer part of the flexor profundus

digitorum is manifested by absence of flexion in the index finger and feeble flexion in the middle finger. This finger is usually influenced by the movement of the ring finger and at times the deep flexor may be supplied by the ulnar. These defects in flexion may be readily seen when the patient is asked to "make

FIG. 99.—Imperfect clasping of fingers in median nerve palsy

a fist" (fig. 98). The index and middle fingers will then be seen to have their phalanges only slightly flexed. The same defects may be observed by clasping the hands together as in prayer when the index finger will remain extended. Flexion of the proximal phalanges of the fingers may be carried out very well in

FIG. 100.—Imperfect opposition of thumb in median nerve palsy

spite of the paralysis of the lumbricales. Paralysis of the flexor longus pollicis makes it impossible for flexion of the second phalanx of the thumb to occur.

Paralysis of the thenar muscle is shown by very defective apposition and abduction of the thumb at right angles to the palm.

Supplementary Movements

In addition to the supplementary movements of pronation which have been mentioned above, they occur commonly in flexion of the proximal phalanges of the two outer fingers. The fact that the flexor profundus digitorum for the middle finger may in some instances receive its supply from the ulnar, explains the frequent presence of flexion of the first phalanx of that finger, inasmuch as the lumbricales have their origin in the tendon of the flexor profundus digitorum. If they are paralyzed, and especially if some contracture and shortening has taken place, contraction of the flexor profundus digitorum will produce a pull on the inert lumbricales and result in flexion of the proximal phalanges. That there is a pull exerted on the lumbricales seems to be shown by the fact that flexion of the proximal phalanx is stronger when combined with flexion of the terminal phalanges than when performed alone. The lumbrical muscles of the middle finger likewise receive their nerve supply from the ulnar. As was seen in paralysis of the extensors of the hand wherein flexion of the fingers pro-

Fig. 101.—Opposition of the thumb by the adductor pollicis and flexor brevis pollicis in median nerve palsy

duced a passive extension at the wrist, so under certain conditions the interossei may produce movements ordinarily subserved by the lumbricales. The interossei when extended produce a pull on the tendons of the flexor profundus and sublimis digitorum, and when the lumbricales are paralyzed, especially if they are shortened afterwards, passive flexion of the proximal phalanges will occur. This mechanism permits full extension of the terminal phalanges, and in median nerve lesions extension of the terminal phalanges of the middle and index finger. It is to be noted that despite the paralysis of the flexors in a median nerve lesion, the position of the fingers is frequently one of flexion and not of extension. Flexion of the second phalanges of the two inner fingers occurs only a little more weakly than normal as the result of the accompaniment of this movement to the normal flexion of the proximal and distal phalanges of these fingers. Flexion of the second phalanx of the middle finger is frequently present in this general flexor movement; it is influenced by flexion of the ring finger; the flexor sublimis digitorum for this finger in some instances must receive some of its nerve supply from the ulnar. Flexion of the terminal phalanx of the index finger is always absent. Flexion of the terminal phalanx of

the middle finger may be present in those cases where the flexor profundus digitorum is supplied by the ulnar nerve. Extension of the wrist produces slight passive flexion of the fingers which is better observed in combined lesions of the ulnar and median nerves. Flexion of the terminal phalanx of the thumb may be simulated by a rebound following extension of the phalanx. Apposition of the thumb to the little finger may be simulated by the action of the adductor pollicis combined with the inner head of the flexor brevis pollicis and flexion of the terminal phalanges of the finger being opposed. It should be insisted upon that abduction when tested should occur at right angles to the palm.

When the metacarpophalangeal joint of the thumb is partially ankylosed so that no flexion or extension of the plane of the thumb is possible, traction of the extensor longus pollicis and the extensor ossis metacarpi pollicis produces abduction of the thumb at right angles to the palm.

Incomplete Lesions

Benisty [15] states that the flexion of the index finger is the most defective movement, though apposition of the thumb is very poor as well. There is frequently imperfect flexion of the middle finger and of the second phalanx of the thumb. The pronators and flexors of the wrist are either not affected at all, or very slightly.

The flexor carpi radialis was found to be rarely involved in the peripheral nerve lesions of the American wounded. This finding is in conformity with that of other observers. Of the small hand muscles the opponens was the most frequently affected.

Careful dynamometric study shows that physiologic interruption can not be differentiated from anatomic section by the strength of the movement of the phalanges of the fingers, because of supplementary motility. Although in a considerable number of cases the movements of the index finger were stronger, this did not allow one to determine the character of the lesion. Return of function in the opponens pollicis would indicate a partial lesion, but because of supplementary motility it is very difficult to determine.

Recovery

Benisty believes that recovery of function of the muscles in lesions of the median nerve takes place in complete and partial lesions in very much the same way. The pronator and palmar muscles regain their function and activity first, then the flexors of the middle finger, and afterwards the flexors of the thumb. Flexion of the index finger and afterwards the flexors of the thumb. Flexion of the index finger and apposition of the thumb are impaired for a very long time. Stopford's [22] statistics show that in 14 cases of suture of the median nerve in the lower third of the forearm the abductor brevis pollicis recovered first in 5 cases; of 10 cases at the bend of the elbow above the motor branches, in 1 case the pronator and flexor carpi radialis recovered first, in 3 cases the abductor brevis pollicis; in 8 cases of suture in the arm the pronator radii teres, flexor carpi radialis, and palmaris longus recovered in 1 case and the abductor brevis pollicis in 3. Among the American injured recovery occurred

first in the flexor carpi radialis and flexor longus pollicis. Movement seemed to begin to return early in the flexor of the index finger, but from a study of residual paralysis it was evident that flexion of the index finger remained imperfect

Fig. 102.—Closure of fist in recovered median palsy

for a very long time, comparable, therefore, to the opponens pollicis. Where recovery occurs in the small hand muscles, the opponens is the last to recover.

Complete recovery of the median nerve may be demonstrated by the ability to completely flex the thumb and index finger in making a fist or in clasping the hands. Figs. 102, 103.

Fig. 103.—Recovery of median nerve

Painful Lesions of the Median Nerve

A very large number of lesions of the median nerve are characterized by the predominance of pain. This painful type of lesion was noted during the Civil War by S. Weir Mitchell,[14] who, subsequently, described its intensity and character under the name of causalgia.

The motor disturbances usually are slight, and total paralysis of all the muscles below the level of the wound is of rare occurrence. Some weakness in movement, however, is always present, usually localized in the flexors of the finger but particularly the index finger and of the thenar muscles. Much of the weakness is due to the pain which is increased upon movement. Involuntary movement, consisting of an irregular tremor of the thumb and index finger, but noticeable in all the fingers, is characteristic of these painful lesions.

FIG. 104.—Causalgia in median nerve lesion combined with ulnar lesion

ULNAR NERVE

In ulnar nerve lesions the appearance of the hand is quite characteristic There is noticed an atrophy which is at times very marked at the first dorsal interosseous space and to a lesser degree at the other spaces; the hand assumes a claw shape, the result of the unopposed action of the extensor communis digitorum. Sometimes clawing may be plainly seen in the little finger but can hardly be seen in the ring finger; at times the middle finger is clawed as well as the ring and little fingers. The hypothenar eminence shows considerable atrophy, and palpation gives the impression of a hollow rather than an eminence. Atrophy of the abductor of the thumb may be made out at the inner part of the thenar eminence.

Paralysis of the flexor carpi ulnaris may be made out by inspection and palpation of the flexors of the wrist when the patient flexes the wrist against resistance. Paralysis of the flexor profundus of the little and ring fingers may be demonstrated by the imperfect flexion of the ring and little fingers in having the patient try to make a fist. The flexion produced at the metacarpophalangeal and second interphalangeal joints results from the influence exerted upon all segments of the finger when the flexor sublimis contracts. Flexion of the distal phalanges of these fingers often is practically nil. Paralysis of the hypothenar muscles is shown by an inability to flex the proximal phalanx of the little finger the distal phalanges being extended. Paralysis of the interossei and of the inner two lumbricales produces the characteristic claw hand. Although all the interossei may be paralyzed, there is complete clawing only of

FIG. 105. Ulnar nerve lesion

the fourth and fifth fingers and sometimes of the middle finger. The reason for this is clear, inasmuch as the first two lumbricales which are supplied by the median are unparalyzed. Extension of the distal phalanges of the fingers is very feeble in the index and middle and practically impossible without supplementary motility in the ring and little fingers. Aside from supplementary movement, the lateral movements of adduction and abduction are lost in the middle and ring fingers and often in the little finger. They are much diminished in the index finger. Paralysis of the adductor pollicis and of the inner head of the flexor brevis pollicis produces defects in prehensile movements, attention to which has been drawn by Duchenne [4] and recently by J. Froment.[23] If the patient is asked to grasp any object between his thumb and index finger, such as a folded newspaper, and told to hold it tightly he vigorously flexes the second phalanx of the thumb and presses the tip awkwardly against the outer margin of the first phalanx of the index finger. This is Froment's sign of the newspaper.

FIG. 106.—Ulnar "paper sign"

Partial Lesions

Lesions of partial, incomplete, or dissociated paralysis of the ulnar nerve are very frequent. The commonest type, according to Benisty, is paralysis of the interosseii and hypothenar muscles, with simple paresis of the flexor profundus and flexor carpi ulnaris. In our World War cases it was observed that whether we were dealing with a lesion in the arm or the forearm the same order of frequency of paralyzed or weak muscles existed. Those muscles paralyzed most frequently were, as noted by Benisty, the hypothenar group and the interossei group. The order of frequency of involvement was as follows: (1) All muscles weak; (2) hypothenar interossei paralyzed; (3) all muscles paralyzed; (4) abductor pollicis paralyzed. When the long flexors were involved all the muscles were weak. Careful dynamometric examination showed that physiologic interruption could not be distinguished from anatomic section by strength of movements of the phalanges in the fingers. In partial lesions relatively greater strength in the phalanges was observed, but at times was an inaccurate guide to the severity of the lesions. Relatively greater strength in the first dorsal interosseus or in the abductor of the little finger proved to be an accurate guide as to the completeness of the lesion.

Supplementary Motility

Flexion of the distal and proximal phalanges of the ring and little fingers is performed by the two inner tendons of the flexor profundus digitorum and the two inner lumbricales, respectively. Imperfect flexion of these phalanges may result from the influence exerted on all segments when the flexor sublimis digitorum contracts. This is more marked in the little than in the ring finger.

Slight flexion of the proximal phalanx of the ring finger may be obtained from the contraction of the flexor profundus digitorum pulling on the lumbricales muscle, which has part of its origin from the tendon of the profundus. Although the interossei which extend to the second and third phalanges of all fingers are paralyzed, inability to extend these phalanges in the index and middle finger is rare. Benisty[15] attributes this to the preservation of the lumbricales, which she states extends the second and third phalanges, and the

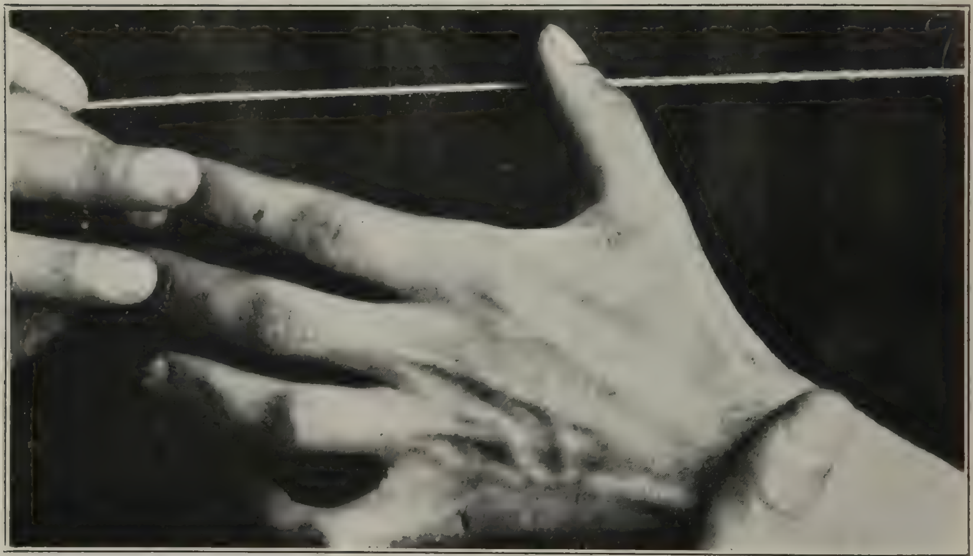

Fig. 107.—Extension of the distal phalanges of the index and middle fingers in ulnar palsy

interossei. With this MacKenzie[16] disagrees and he is inclined to believe that the dorsal interossei for the index and middle fingers receive some of their nerve supply from the median. Besides this, he believes that with hyperextension of the proximal phalanx, there is an alteration in the line of pull of the interossei which become angular instead of straight, and that an extended proximal phalanx forms a rigid dorsal support for the sublimis tendon, thus increasing its flexion pull. Therefore, paralysis of the lumbricales alone would produce at one time overaction of flexion of the second phalanx and a poor mechanical principal for extension of the distal phalanges. Other factors, however, enter into the production of extension of the second and third phalanges of the index and middle fingers. Duchenne,[4] Benisty,[15] and MacKenzie[16] contend that the extensor communis digitorum does not produce extension of these phalanges. On the other hand, Beevor[5] points out that although it was true that when the extensor digitorum was paralyzed the second and third

phalanges could be extended, and when the interossei were paralyzed claw-hand occurred and extension of the second and third phalanges was impossible, yet if in the latter case the third phalanges were passively flexed, the second and third phalanges could be extended. He says it is probable that in claw-hand the inability of the extensor digitorum to extend the terminal phalanges is due to its energy being expended on the first phalanges, which are not prevented from over-extension by the lumbricales which are paralyzed.

The following factors enter into preservation of extension of the second and third phalanges: Innervation of the first and second dorsal interossei by the median, passive extension of the second and third phalanges by flexion of the proximal phalanges, thereby shortening the interossei. If the interossei are paralyzed and the lumbricales preserved, the pull on the interossei is straight and not angular; under these conditions, contraction of the extensor communis

FIG. 108.—Abduction of the thumb by the extensor longus pollicis in ulnar palsy

digitorum may exert a pull on the inert interossei and produce extension of the second and third phalanges. Some pull on these interossei may be exerted by the extensor communis digitorum even if these conditions are absent, as may be seen in combined ulnar and median lesions. The fact that the extensor communis digitorum exerts a pull on the inert interossei does not mean that it is at all concerned with the normal extension of the second and third phalanges, which may be the result of an entirely independent contraction of the interossei.

In adduction of the thumb, as pointed out by Duchenne, the extensor longus pollicis is the prime mover, and in ulnar nerve lesions it may supplant the loss of the adductor pollicis.

Abduction of the fingers away from the midline may result from forced extension of the first phalanges. It is very marked in the index and little fingers. Slight adduction results from flexion of the first phalanges. Both of these movements have been known for a long time. The reason for the preservation of lateral movements in the middle and index fingers is given by

Benisty[15] as the preservation of the lumbricales, as well as the extensor action of the first phalanges. As MacKenzie[16] points out, the lumbricales are not concerned with lateral movements of the fingers. The preservation of lateral

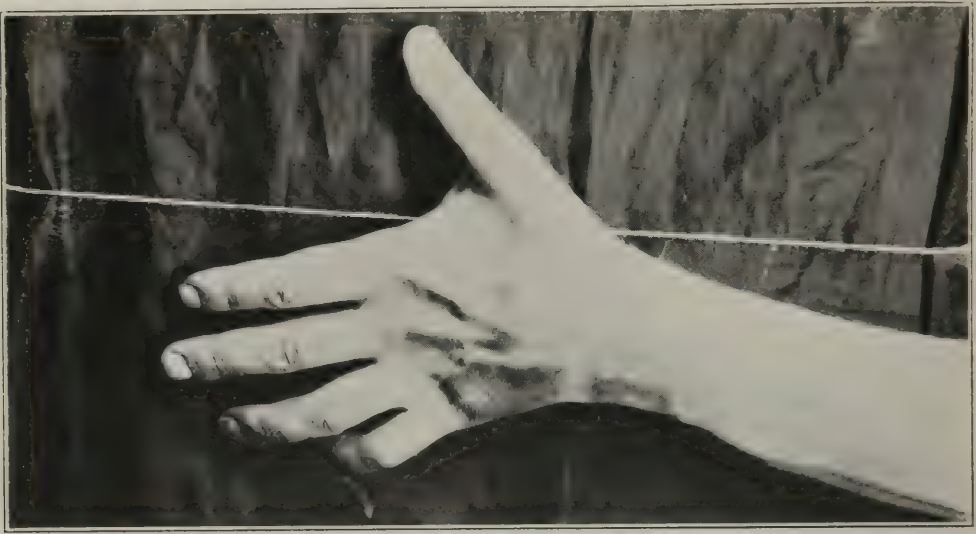

FIG. 109 Abduction of fingers by forced extension

movements of these two fingers is due, in addition to the extensor movements of the first phalanges, to a dual nerve supply, as it has been noted on a number of occasions that the first dorsal interosseus is partially preserved in complete ulnar section. Besides the abduction observed in forced extension of the first

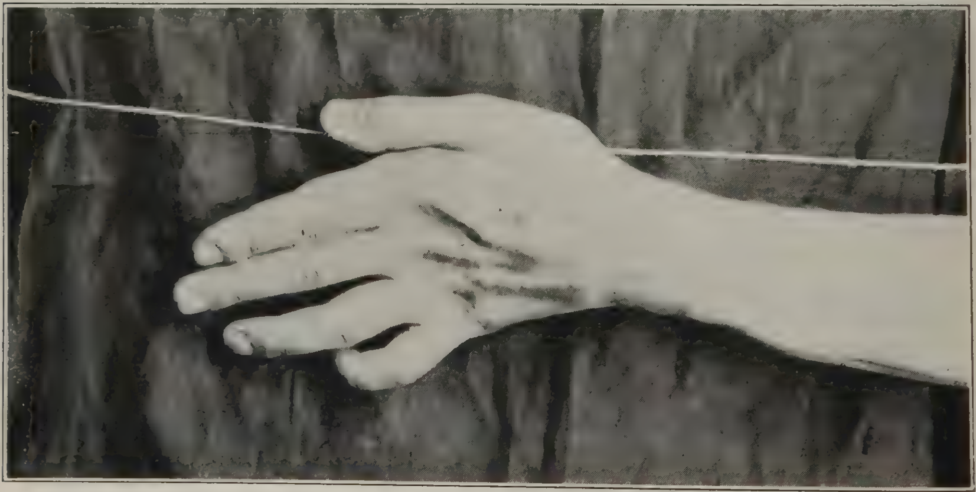

FIG. 110.—Adduction of index finger by extensor indicis with hand in ulnar deviation

phalanx, abduction movement of the index finger can be produced by strong contraction of the extensor ossis metacarpi pollicis and extensor brevis pollicis; the first dorsal interosseous having part of its origin on the metacarpal bone of

the thumb, is pulled outward by extension of this bone and produces abduction of the index finger. When the hand is abducted to the ulnar side, the tendon of the extensor indicis is so deflected that its contraction produces slight adduction of the index finger.

Recovery

The order of recovery in ulnar nerve lesions given by Benisty [15] is flexor carpi ulnaris, flexor profundus digitorum, then the small hand muscles, which recover very slowly. The committee upon injuries to the nervous system of the Medical Research Council [24] stated that better functional recovery is to be expected in the flexor carpi ulnaris, flexor profundus digitorum, and in the abductor minimi digiti than in the other muscles. Because of supplementary motility the strength of movement of the phalanges themselves is a misleading sign of recovery. In our cases it was found that recovery occurs more regularly in the flexor carpi ulnaris and late in the small hand muscles, but that the abductor of the thumb recovers more frequently than the abductor of the little finger.

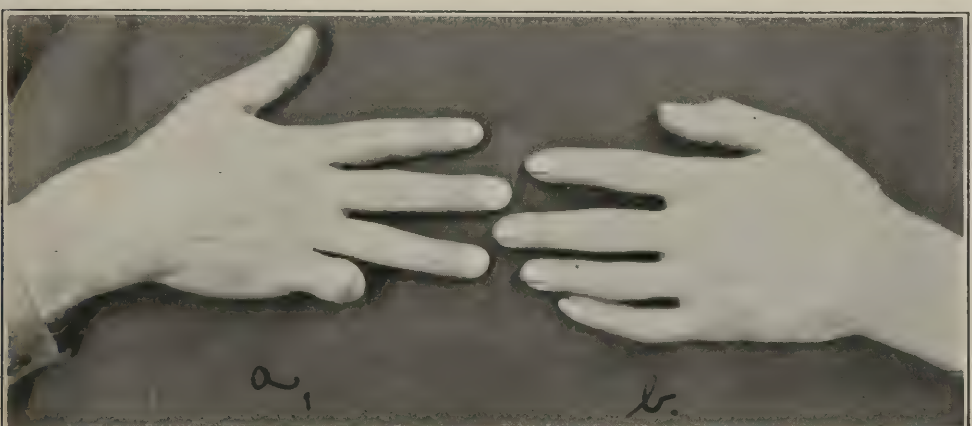

FIG. 111.—Pitres test for recovery from ulnar palsy. *a*, Normal movement; *b*, failure of test in ulnar palsy

Signs of Recovery

Complete recovery may be shown by the following sign described by Pitres [21]: The palm being placed flat upon the table with the fingers abducted, the patient can move the little finger inward and outward and then scratch the top of the table with the nail of his little finger without moving his wrist.

MEDIAN AND ULNAR NERVES COMBINED

Total Paralysis

The only movements possible in combined lesions of the median and ulnar nerves in the muscles supplied by these nerves are those occurring as the result of supplementary motility. The appearance of the hand is characteristic. The wrist is slightly hyperextended on the forearm and the hand

inclines to the radial side, the thumb is in the abduction and on a plane with the palm. The first phalanges of the fingers are moderately extended on the metacarpus, and slight passive flexion of the last two phalanges occurs. The thenar and hypothenar eminences are markedly atrophic.

FIG. 112.—Ulnar and median nerve lesion

Supplementary Motility

Slight passive movement of flexion at the wrist is produced by hyperextension of the hand with sudden relaxation. Active contraction of the abductor longus pollicis assists in carrying out this movement of flexion. At times this muscle is capable of producing flexion in the absence of relaxation

FIG. 113.—Flexion of the wrist by the extensor ossei metacarpi pollicis

following hyperextension. Flexion of the fingers is similarly performed by hyperextension of the hand and extension of the fingers which are then relaxed. Slight abduction of the fingers may be produced by energetic contraction of the extensors.

Partial Lesions

Partial lesions of the ulnar and median nerves produce many interesting types of dissociated paralysis. A number of these have been described by Benisty:[15] One, in which the small hand muscles and flexors of the fingers alone being paralyzed; another in which there is in addition to the paralysis of the small hand muscles, a paresis of the flexors which produces a very marked clawing. A number of other types have been described but their recognition is of no great importance. Careful dynamometric studies show that when observed some time after injury anatomic section of both ulnar and median nerves produced complete paralysis of all of the phalanges of the fingers and thumb and severe lesions, not anatomic sections, show some movement in some of the phalanges of all of the fingers. In incomplete lesions of either ulnar or median nerves weak movements of the phalanges of the fingers, if interpreted alone, are insufficient guides to whether one of these nerves is severed, and if severed, which one. Because of the widespread supplementary motility, recovery of function is difficult to study and a definite pattern of involvement can not be determined.

MUSCULOCUTANEOUS NERVE

In paralysis of the musculocutaneous nerve satisfactory flexion can be produced by the voluntary action of the brachio radialis supplied to the mus-

FIG. 114.—Musculocutaneous paralysis

culospiral. The pronator radii teres is also a flexor of the forearm, and in some cases has efficiently produced flexion in combined paralysis of the musculocutaneous and musculospiral nerves. Evidence of paralysis of the musculocutaneous nerve may be determined by palpation of the biceps when flexion of the forearm is resisted, with the forearm in position between pronation and supination.

CIRCUMFLEX NERVE

The muscles supplied by the circumflex nerve are the teres minor and deltoid. When the deltoid muscle is completely paralyzed abduction of the arm is impossible.

FIG. 115.—Circumflex nerve palsy. Greatest adduction

SUPPLEMENTARY MOTILITY

Satisfactory abduction of the arm when the circumflex nerve is completely paralyzed occurs very frequently. The frequency may be seen from the report of Bunts,[25] who, in 1903, found that in 19 cases of circumflex nerve paralysis 7 patients recovered function.

Of the seven, four recovered function in the absence of the deltoid muscle. From studies of clinical cases and preparations of anatomic models, it appears that there are two distinct types of supplementary motility which permit abduction of the humerus in complete paralysis of the deltoid muscle. Of course, the movement of torsion or bending of the spine need not be included, as it only increases the distance between the extended hand and the ground and in no way abducts the humerus. The movement of abduction backward seems never to be supplemented, so that such a movement as is necessary to put one's hand in the hip pocket is impossible.

The first type of supplementary movement is that in which the head of the humerus is firmly fixed in the glenoid cavity, probably by the subscapularis, the infraspinatus, the pectoralis major, and the supraspinatus. During this

period external rotation of the humerus occurs. The serratus magnus and trapezius, with the rhomboidei and the levator anguli scapulæ then produce the rotation of the scapula, elevating the humerus; some actual abduction may likewise occur. Thus the first and second phases of abduction are combined but the second phase overshadows the first. The third phase may be concluded by the supraspinatus, the clavicular head of the pectoralis major, and the coracobrachialis.

The second type is that in which the first phase of abduction of the humerus may occur as the result of combined action of the supraspinatus, the infraspinatus, and probably acting in conjunction with the coracobrachialis and possibly the long head of the biceps; the second phase of abduction occurs as

FIG. 116. Complete adduction of arm by supplementary movement in circumflex nerve palsy

in the normal individual, by the action of the serratus magnus, the trapezius, the rhomboidei, and the levator anguli scapulæ; the third phase is completed by the coracobrachialis, the clavicular head of the pectoralis major, and the supraspinatus.

BRACHIAL PLEXUS

Brachial plexus lesions in civil practice have been divided as to type into lesions in the primary cords, the secondary cords, and root lesions. The secondary cords, usually spoken of as the cords of the brachial plexus, have been the most frequent type of lesions observed. Some of the cases have been classified into upper-arm paralysis, the Erb's type of injury involving the fifth and sixth cervical roots, and the lower-arm paralysis, or the Klumpke-Dejerine type, producing a paralysis of the common median and ulnar nerve trunks. Direct lesions of the brachial plexus due to war wounds present no clearly defined classification. Ordinarily, immediately following the injury there is complete paralysis of the whole brachial plexus which, as the effects of the concussion disappear and the changes due to hemorrhage and infiltration diminish, revolves itself into one or another type of involvement of one or more cords, or an incomplete type of total brachial plexus paralysis.

As in civil practice, an involvement of the upper primary cords produces a paralysis of the fifth and sixth cervical roots, known as Erb's paralysis. The muscles affected by paralysis resulting from this lesion are the deltoid, biceps, brachialis anticus, supinator longus, as well as the supraspinatus and infraspinatus, the rhomboideus, and subscapularis, the clavicular fibers of the pectoralis major, serratus magnus, and, finally, the latissmus dorsi and teres major.

FIG. 117.—Erb's form of brachial plexus palsy analgesia (black) of fifth and sixth cervical segments

The arm can not be flexed at the elbow on account of the paralysis of the flexors of the forearm, and can not be raised or abducted on account of paralysis of the deltoid. The movements of the wrist and fingers are not interfered with. The arm is weak in adduction and it can be rotated only inward or outward or not at all. The rhomboid muscle stands out less prominently in its attempts to oppose the two shoulder blades. The patient is able but feebly to put the affected hand on the buttock of the same side.

FIG. 118.—Brachial plexus lesion affecting common trunk of ulnar and median nerves

The paralysis resulting from a lesion of the common trunk of the median and ulnar nerves need not be described as it differs in no way from a combined lesion of these nerves. Lesions of the inner cord of the brachial plexus are

evidenced by paralysis of all the intrinsic muscles of the hand and some or all of the flexors of the wrist and fingers.

Lesions of the posterior cord are evidenced by paralysis of the muscles supplied by the circumflex, musculospiral, and subscapularis nerves. Lesions of the outer cord result in a paralysis of the muscles supplied by the musculocutaneous and median nerve, with the exception of the intrinsic muscles of the hand.

In addition to these clearly defined types of paralysis there may be a more complicated paralysis involving the whole, or nearly the whole, of the brachial plexus. It is to be noted that lesions of the brachial plexus have a general tendency to recover. Often this recovery is only partial and definite paralysis of one or two nerves or some muscles may be permanent. It is necessary, therefore, to continue the observation for several months, both clinically and

FIG. 119.—Partial lesion of whole brachial plexus, affecting chiefly posterior and outer cords

electrically, to estimate the recoverability of certain muscles involved in these partial lesions.

One of the interesting things observed in lesions of the brachial plexus has been the coincidence of lesions of the spinal cord with these injuries. In this type there is almost always injury by projectiles which pass through the neck, either from left to right or right to left. The symptoms which appear at once are that the patient falls forward without losing consciousness, and all four extremities are paralyzed. A few days or a week after the accident, according to the gravity of the injury, the lesion subsides in one entire half of the body, opposite the brachial monoplegia. The leg on the affected side then recovers and the brachial monoplegia alone remains, often severe, persisting for a long time and improving very slowly. At times a paralysis of the opposite arm of a root type may persist for a certain period.

The loss of power as the result of the brachial plexus lesion is most marked in the hands and fingers.

Frequently the picture is completed by a paralysis of the cervical sympathetic or Horner's syndrome, enophthalmos, narrowing of the palpebral fissure and myosis. This very frequently is intermittent and often disappears early.

SCIATIC NERVE

Although the internal and external popliteal nerves run separately up to the lumbosacral plexus, above the popliteal space they are bound together by connective tissue so closely that lesions above the popliteal space may be considered as lesions of the sciatic nerve.

FIG. 120.—Sciatic nerve palsy

Motor branches are given off the sciatic nerve trunk from above downward to the semitendonosus, semimembranosus, the long head of the biceps, short head of the biceps, and adductor magnus. The musculocutaneous branch of the external popliteal supplies the peroneus longus and peroneus brevis; the anterior tibial branch supplies the tibialis anticus, extensor longus digitorum, extensor proprius hallucis, peroneus tertius and extensor brevis digitorum. The muscular branches of the internal popliteal go to the gastrocnemius, popliteal, plantaris and soleus, while the posterior tibial innervates the popliteus, the deep part of the soleus, tibialis posticus, flexor longus digitorum and flexor longus hallucis. The internal plantar nerve supplies the abductor hallucis, flexor brevis hallucis, flexor brevis digitorum, flexor accessorius and the two first lumbricales. The external plantar nerve supplies the interossei, the muscles of the little toe, the third and fourth lumbricales, and the adductor obliquus et tranversus hallucis. Because the nerve to the semitendonosus is given off very high rarely is there a complete paralysis of flexion of the leg. As a rule, flexion is only diminished in strength and the diminution of strength is in the biceps, the semitendonosus or the semimembranosus being less affected. In appearance the foot dangles and drops. Frequently there is observed a marked atrophy of all the muscles below the knee. No active movement is possible in the muscles below the knee.

Supplementary Motility

Interpretation of muscle function in the lower extremity is much simpler than that in the upper, chiefly because of the minor importance of the intrinsic foot muscles as compared with those in the hand. Attention, therefore, centers chiefly in the movements of the larger muscles in the lower extremity. Inasmuch as supplementary movements can occur only when one of the divisions of the sciatic nerve is totally paralyzed and the other partially or not at all involved, description of these movements are made under the heads of the external popliteal nerve and the internal popliteal nerve.

Partial Injury

Dissociated or partial paralysis may be due to greater damage to either the internal or external popliteal branches or partial injury to both. Operative and clinical experience shows that the external popliteal suffers greater damage, as a rule, than does the internal popliteal. Of a series of 37 cases seen soon after injury the external popliteal was paralyzed and the external popliteal was weak in 12 cases; all the muscles were weak in 10 cases; the internal popliteal was paralyzed and the external popliteal was weak in 4 cases; the external popliteal alone was paralyzed in 2 cases, the internal popliteal alone in 2 cases, and only the extensors of the toes in 2 cases; all muscles were paralyzed in 2 cases.

Recovery

According to Benisty,[15] the muscles which are the first to recover are usually the tibialis anticus, the peroneus longus, or the gastrocnemius; very much more rarely recovery begins in the tibialis posticus. The flexors and extensors of the toes are always the last to recover.

The Medical Research Council of Great Britain[21] reported that, as a rule, the internal popliteal nerve shows signs of return of function earlier than does the external popliteal. Stopford's[22] records of sutured cases show that the order of recovery is the gastrocnemius, tibialis anticus, extensor longus digitorum, extensor proprius hallucis.

The records of the Military Orthopedic Hospital, Shepherd's Bush, gives the order of recovery in eight cases as tibialis posticus, gastrocnemius, tibialis anticus, extensor longus digitorum, extensor longus hallucis, extensor brevis digitorum, and peroneus longus.

In a group of 41 of our recovered cases there was a return of function in the tibialis anticus in 18 in the gastrocnemius in 11, in all muscles in 9, in the tibialis posticus in 8, in the peronei in 4, in all muscles supplied by the external popliteal in 3, in the flexors of the toes in 1, and in all muscles supplied by the internal popliteal in 1 case. In 14 cases following suture, function returned first in the gastrocnemius in 8 cases, in the tibialis posticus in 5 cases, in the peronei in 4 cases, in the flexors of the toes in 3 cases, in the tibialis anticus in 3 cases, and in the extensors of the toes in 1 case. In severe cases, and following suture, return of function in the branches of the internal popliteal occurred earlier than in those of the external popliteal; extension of the toes was very late in appearing, and in spontaneously recovering lesions flexion of the toes occurred very late.

Painful Lesions

As was noted above under the median nerve, so in the sciatic nerve some injuries result in a painful type of paralysis. It has been found that only such injuries are painful as show an involvement of the fibers of the internal popliteal nerve.

During the first week after injury complete paralysis is often present. Then motor recovery begins, most often in the region of the internal popliteal. In some cases, however, where the external popliteal branch is less severely injured, movements controlled by this nerve are the first to recover. As with the median nerve, involuntary movements are sometimes observed, consisting of abduction and adduction of the foot or flexion of the toes.

EXTERNAL POPLITEAL NERVE

Somewhat analogous to the musculospiral nerve, the external popliteal nerve, when injured, produces immediate and extensive paralysis of all the muscles supplied by it. As the result of this injury a deformity characterized by foot-drop is observed. In addition to the foot-drop a slight drop of the first phalanx of all the toes may be seen. At times a dorsal tumor of the tarsus is observed. This is usually due to the more or less pronounced projection of the heads of the astragulus and scaphoid bones and to the thickening of the sheaths of the extensor tendons.

Fig. 121.—External popliteal nerve palsy

When examining voluntary motion it is necessary to immobilize the knee of the patient and to be alert lest twitchings of the aponeurosis of the leg caused by contraction of the muscles of the thigh be mistaken for contraction of muscles supplied by the external popliteal nerve. When carefully observed, no active movement of dorsal flexion of the foot is possible. Abduction of the foot is executed by the tibialis posticus. Extension or dorsal flexion of the proximal phalanges of the toes is impossible. The distal phalanges may be extended by the contraction of the interosseus tendon which in the foot as in the hand extends the last two phalanges. Abduction of the foot can not be performed.

Supplementary Movement

Supplementary movements of the ankle joint are fairly frequent. Strong flexion of the toe occasionally results in inversion and slight dorsal flexion of the foot, due to a mechanism similar to that observed in which strong flexion of the fingers produces passive extension of the hand in musculospiral lesions. Movements of the toes are sometimes confusing when the contraction of the antagonists of the paralyzed muscle is followed by a rebound simulating the normal action of the muscles under investigation. If the dorsal flexors of the toes are paralyzed and the patient attempts to contract the paralyzed muscle, plantar flexion of the toes may be the initial movement followed by a rebound of the toes to the original position.

Partial Lesions

Cases of incomplete and dissociated paralysis are met with infrequently. They generally occur following wounds in the leg in which either the musculocutaneous or the anterior tibial nerve alone has been injured. Dissociated paralysis may occur, however, in lesions above the bifurcation of the nerve. Under this condition we may have a paralysis of the tibialis anticus alone, or of the peronei muscle alone, the extensors of the toes being spared. Occasionally the extensors of the toes may be paralyzed and the other muscles not at all or very slightly involved.

Recovery

The order of recovery is given by Benisty [15] as tibialis anticus, peronei, extensor longus digitorum, and extensor proprius hallucis. Stopford [22] agrees with this, whereas the records of the Military Orthopedic Hospital put the extensor longus digitorum first. Among 29 American cases spontaneously recovering, the tibialis anticus recovered in 22 cases, the peronei in 7, the extensor longus digitorum in 3, and the other muscles in 3. In 6 cases showing recovery out of 27 cases sutured, the order was tibialis anticus, extensor longus digitorum, and the peronei.

INTERNAL POPLITEAL NERVE

In lesions above the popliteal space complete isolated injury to the internal popliteal nerve is rare. More frequently, as noted above under lesions of the sciatic nerve, partial or dissociated paralysis of the nerve, accompanied by more or less complete paralysis of the external popliteal nerve occurs. In lesions below the popliteal space the internal popliteal may be completely severed. Motor disturbances which result are paralysis of plantar flexion of the foot. Frank adduction of the foot is impossible; it is always accompanied by elevation of the foot and is then due to contraction of the tibialis anticus. Flexion and separation of the toes are abolished and no muscle or tendon in the sole can move.

POSTERIOR TIBIAL NERVE

Paralysis of this nerve frequently occurs as the result of injury in the calf and produces a paralysis of all the muscles of the sole. This is very frequently a painful paralysis of a causalgic nature.

46997—27——60

Fig. 122.—Anterior crural palsy.

ANTERIOR CRURAL NERVE

All the muscles supplied by the anterior crural nerve are paralyzed as the result of injury striking the actual trunk of the anterior crural at the highest part of the thigh below Poupart's ligament. Usually some of these muscles are preserved and the most frequent nerves to be involved are the nerves to the quadriceps and the internal saphenous nerve. A lesion of the nerve to the quadriceps produces paralysis of this muscle with inability to extend the leg on the thigh. Some extension of the leg on the thigh has been noted by contraction of the tensor fascia femoris, supplied by the superior gluteal nerve.

LUMBOSACRAL PLEXUS

The lumbosacral plexus is very rarely injured except in its root in consequence of a projectile having injured the cauda equina in its intraspinal course inside or outside of the dura mater.

CRANIAL NERVES

TRIGEMINAL NERVE

Lesions of the trigeminal nerve are not uncommon. Usually the lesion involves but one of the branches. Occasionally a paralysis of the masseter or of the pterygoid, or both muscles may be observed. When this occurs, upon clenching the two jaws together the paralyzed masseter does not contract; upon opening the mouth the jaw deviates to the paralyzed side. The same observation holds true in attempting to protrude the lower jaw in front of the upper.

Fig. 123.—Facial palsy

FACIAL NERVE

The facial nerve is fairly frequently injured in wounds of the parotid region and of the neck. Moreover, wounds of the cranium, particularly in the temporofrontal region are very often accompanied by paralysis of the motor filaments of the orbicularis palpebrarum, or the frontalis. Most frequently some of the branches of the seventh nerve are injured alone. Complete paralysis of the seventh nerve is not uncommon and a dissociated paralysis of the seventh nerve from a lesion of the trunk likewise frequently occurs. Paralysis of

the trunk of the seventh nerve is characterized by complete absence of movements of expression on the paralyzed side, with inability to wrinkle the forehead upward or to close the eye, and attempts at closing the eye are associated with movement of the eyeball upward, or Bell's phenomenon. In addition to this, the patient is unable to pucker the lips or to smile or show the teeth on the paralyzed side. The expression of the face is characteristic, the paralyzed side being "washed out" and expressionless, and because of atony the angle of the mouth droops, the nasolabial fold is obliterated, and there is an effacement of wrinkles on the forehead. Frequently because of inability to hold the lips closely together there is drooling. All of the signs are exaggerated during attempted movement of the face or during involuntary movement, as in laughing.

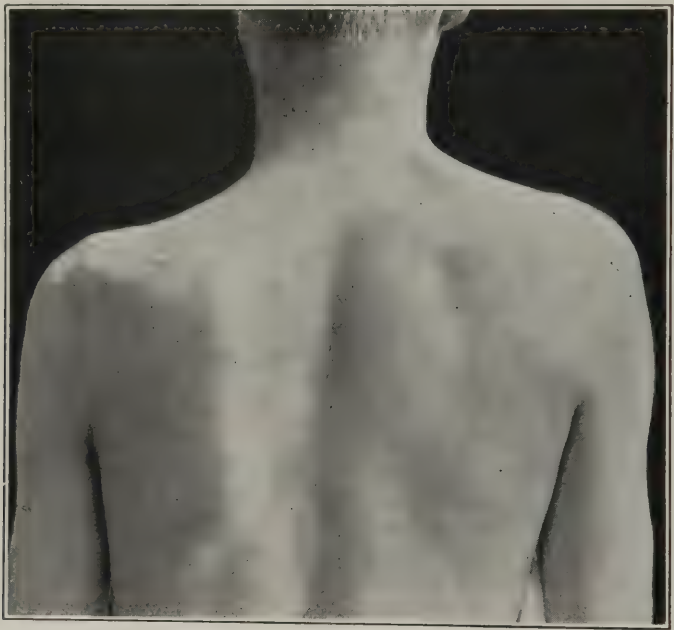

FIG. 124.—Paralysis of trapezius

GLOSSOPHARYNGEAL NERVE

This nerve is rarely injured alone but when injured produces paralysis of the superior constrictor of the pharynx. This is manifested by difficulty in swallowing solids so that the patient is obliged to facilitate this deglutition by the ingestion of fluids. At the same time the soft palate may be involved so that the unparalyzed part of the palate produces deviation to the sound side. When this occurs nasal regurgitation of fluids may be present. When the tongue is held protruded by the examiner, phonation of the broad "a" produces a movement of the posterior wall of the pharynx toward the unaffected side.

PNEUMOGASTRIC NERVE

This is rarely affected alone, but when paralyzed produces a paralysis of the adductor of the vocal cords.

SPINAL ACCESSORY NERVE

When injured alone, usually the external branch only, intended for the innervation of the trapezius and the sternocleidomastoid, is involved. The internal branch, which joins the pneumogastric soon after its exit from the cranium, supplies the muscles of the larynx and those of the soft palate. According to some authors, it is this nerve which, running along with the pneumogastric, produces the motor disturbances due to the injuries of the vagus, this nerve itself being purely sensory. When the external branch is paralyzed there ensues a paralysis of the sternocleidomastoid and the trapezius. On turning the head to the side the paralyzed sternocleidomastoid muscle does not become prominent. The shoulder of the affected side droops, the inner angle of the scapula deviates outward, the outer angle droops, and the lower angle approximates the midline and is projected under the skin. The infraspinous portion of the trapezius receives its innervation from the fourth cervical nerve. Frequently this must course with the branches of the external branch of the spinal accessory, inasmuch as when we deal with lesions of the spinal accessory high in the neck the infraspinous portion of the trapezius is involved as well as the supraspinous portion, and under this condition abduction of the arm is impossible because of absence of fixation of the shoulder. Lesions low in the neck produce only a weakness in the supraspinous portion of the trapezius, and abduction of the arm may often be adequately performed, inasmuch as the infraspinous portion of the trapezius serves to adequately fix the shoulder blade during the first stage of abduction of the arm.

FIG. 125.—Hypoglossal nerve palsy

HPYOGLOSSAL NERVE

The hypoglossal nerve supplying the muscles of the tongue, the geniohyoid muscle, and the subhyoid muscle, is rather frequently injured in the suprahyoid region and more frequently in the lateral pharyngeal space. This lesion is shown by a hemiparesis of the tongue, the corresponding half of the tongue is atrophied and shriveled, and within the mouth it is drawn to the unparalyzed side. When protruded, it points to the paralyzed side.

SIMULTANEOUS INJURIES OF CRANIAL NERVES

Simultaneous lesions of the ninth, tenth, and eleventh cranial nerves have frequently been observed as the result of war injuries and often injury of one or more additional nerves has been present, most frequently the twelfth, occasionally the cervical sympathetic, and rarely the seventh nerve.

Vernet [26] has described a syndrome due to a combined lesion of the glossopharyngeal, pneumogastric, and spinal accessory nerves, called by him the syndrome of the posterior lacerated forearm. Collet [27] described a combination of symptoms due to a complete lesion of the ninth, tenth, eleventh, and twelfth cranial nerves under the name of glosso-laryngo-scapulo-pharyngeal hemiplegia. The same condition was described by Sicard [28] as the syndrome of condylo-posterior lacerated forearm. Villaret [29] described the syndrome of the posterior retroparotid space, which is characterized by the addition of a lesion of the sympathetic nerve to the syndrome of the last four cranial nerves, producing thereby enophthalmos, narrowing of the palpebral fissure and myosis. One of the notable features of all the cases is that whatever other nerves might be affected, the ninth, tenth, and eleventh are rather consistently injured together. Such lesions are produced by wounds in the uppermost part of the latero-pharyngeal space. Simultaneous injury of these nerves usually occurs as the result of a missile passing obliquely from the mastoid region on one side to the malar bone on the other, injuring the three nerves and missing both the carotid and jugular vessels.

FIG. 126.—Syndrome of the posterior retroparotid space, showing paralysis and atrophy of tongue, narrowing of palpebral fissure, myosis, and enophthalmos

The symptomatology of a combined lesion of the ninth, tenth, and eleventh cranial nerves is constant and easily recognized. As a characteristic triad of symptoms indicative of a complete lesion of these three nerves, Vernet proposes nasal regurgitation of fluid, dysphagia of solids, and hoarseness, representing, respectively, paralysis of the palate, pharynx, and larynx.

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Chapter IX

SENSORY DISTURBANCES IN PERIPHERAL NERVE LESIONS [a]

For many years it has been noted that total loss of sensation after complete division of a peripheral nerve is limited to a much smaller area than one would expect from its anatomic distribution. Likewise, it has been observed that following injury of a peripheral nerve sensory symptoms may rapidly diminish and at times loss of sensation to pin prick be entirely absent. That severe, widespread anesthesia results only from trauma of several nerve trunks of a plexus, has generally been accepted. Lesions of single nerves result in partial anesthesia, or, if a severe anesthesia be present, the area of complete loss of sensation rapidly shrinks.

Many attempts have been made to explain these phenomena. Some of the older theories were to the effect: (1) That nerve fibers grow from healthy surroundings into the insensitive parts; [1] (2) that after section of a nerve, stimulation of the severed part may pass through an accessory branch into an adjacent nerve and reach the major branch of the injured nerve above the lesion, through a second lateral branch (collateral innervation); [2] (3) that numerous anastomoses connect the peripheral ramifications of sensory nerves, many cutaneous areas receiving their innervation from different nerves.[3] All these opinions have undergone important changes since the investigations of Head and his coworkers. The results of their studies led Head and Sherren [3] to conclude that the sensory mechanism in the peripheral nerves consists of the following three systems:

(1) Deep sensibility, capable of answering to pressure and to movement of parts and even capable of producing pain under the influence of excessive pressure, or when the joint is injured. The fibers, subserving this form of sensation, run mainly with the motor nerves, and are not destroyed by division of all the sensory nerves to the skin. (2) Protopathic sensibility, capable of responding to painful cutaneous stimuli, and to extremes of heat and cold. This is the great reflex system, producing a rapid, widely diffused response, unaccompanied by any definite appreciation of the locality of the spot stimulated. (3) Epicritic sensibility, by which we gain the power of cutaneous localization, of discrimination of two points, and of the finer grades of temperature, called cool and warm.

Head and Sherren [4] state that in complete division of a mixed nerve, as the median or ulnar, the area it supplied does not become uniformly insensitive. Whereas previous observers have stated that sensation is diminished over the full area usually assigned to the injured nerve and lost completely over a small portion only, they have shown that this diminution of sensation is

[a] The statements of fact appearing herein are based on "Overlap of So-Called Protopathic Sensibility as Seen in Peripheral Nerve Lesions," by Maj. Lewis J. Pollock, M. C., *Archives of Neurology and Psychiatry*, 1919, ii, No. 6, 667.

in reality a total loss of sensibility to stimulation with cotton wool, to the compass test, to the painless interrupted current, and to temperatures between 22° C. and 40° C. In this area are felt only the stimuli affecting the protopathic sensibility, such as the prick of a pin and temperatures below 20° C. and above 40° C. The area rendered insensitive to light touch by division of the median or of the ulnar nerve varies little in extent. In sharp contrast to this slight variation is the extreme difference in surface extent of the loss of sensation to a pin prick which follows division of either of these nerves. "The consequence of both division and irritation of these nerves shows that as far as protopathic sensibility is concerned they overlap to an enormous extent."[5]

It is evident, therefore, that the complete sensory distribution of a peripheral nerve consists of its exclusive supply, or that area in which loss of sensation is produced by its division, and in addition its overlap or the area determined by the limits of skin sensitive to stimuli when all the adjacent nerves have been severed. Head and Sherren, employing the method of residual sensibility, were able to determine the complete sensory distribution of some of the nerves. These areas were part of the distribution of the median, the internal saphenous, part of the external popliteal, the external saphenous and part of the posterior tibial nerves.

The purpose of the present chapter is: First, to record the smallest area of loss to prick pain which follows interruption of the various peripheral nerves; second, to point out the relative smallness of this area as compared to the area of loss to touch; third, to show that the preservation or early return of prick pain as compared to tactile sense is due to the assumption of function of adjacent nerves, and not to nerve regeneration, as interpreted by Head; and, fourth, to outline the total sensory distribution of some of the peripheral nerves by residual sensibility.

MATERIAL

Observations were made on 500 patients with peripheral-nerve lesions seen early in base hospitals in France, and 520 patients with peripheral-nerve lesions studied later at United States Army General Hospital No. 28, Fort Sheridan, Ill.

The observations of early peripheral-nerve lesions were in most instances uncontrolled by operative procedures. The major portion of the lesions were partial and frequently complicated by injuries to adjacent small sensory branches. But these observations served a useful purpose. They showed: (1) That in many cases for the first two or three weeks only a very small area within the border of the part insensitive to cotton wool was sensitive to pin prick; (2) that in a few a larger zone sensitive to pin prick appeared within 15 days; and (3) that the return of sensitiveness to pin prick in a larger zone, corresponding to the area which was later determined as overlap, usually was found, at times variable from 30 to 100 days. The cases showing return to pin prick over a large area in less than 30 days were predominantly cases of radial and musculospiral lesions.

The material of peripheral-nerve lesions studied later may be divided into two groups: The first, a group of 391 cases uncontrolled by operation, and in

the majority of instances recovering spontaneously; the second, a group of 129 cases controlled by operation, which may be tabulated as follows:

Nerve lesions	Number
Ulnar	20
Radial	31
Median	9
Ulnar and median	15
Median and radial	2
Musculocutaneous, ulnar, and median	2
Brachial plexus	2
Great sciatic	20
External popliteal	25
Anterior tibial	2
Ulnar, median, and internal cutaneous	1
Total	129

General impressions relative to the sensory changes in peripheral-nerve lesions were derived from the whole material. The areas of total nerve supply and of overlap were obtained only from cases certified by operation. The cases which have been used in the study of regeneration of nerves likewise were certified by operation. Therefore, although the whole 1,020 cases contributed to the general conclusions concerning these problems, only one group, consisting of the cases coming to operation, was employed in obtaining the data which serve as the basis for the special conclusions contained herein.

METHODS OF INVESTIGATION

The problems under investigation were not studied from a psychological standpoint. The areas of overlap were found in the course of clinical examinations of a large group of cases. The methods of examination, therefore, were those ordinarily used clinically. The sense of touch was tested by a wisp of cotton. The sensation of pain in response to the prick of a pin was ascertained by using a weighed needle sliding within a bit of glass tubing so that with different weighed needles a pressure of from 5 to 35 grams could be applied.

Although in this chapter temperature sense will not be referred to because of the difficulty of standardizing methods and the impossibility of employing the finer methods clinically, it may be stated that for the rough examination of sense of cold, a pledget of cotton twisted to a point and saturated with ether was used. This method permits a less diffuse type of stimulation and has the advantage of ease and simplicity. For physiologic research this method is, of course, inapplicable. Light touch with a wisp of cotton to determine sense of touch may be accepted if the exact threshold of sensation is not under investigation, and if exact borders of loss of sense of touch be not insisted on. For the purposes of this investigation, the exact borders of loss of sense of touch need not be insisted on. Only one factor must be considered in this method of examination, namely, return of so-called hair sensibility must not be confused with touch; hence, in testing for touch where an accurate border was to be determined, the parts were closely shaven.

The degree of pressure which it is permissible to employ in determining prick pain without jeopardizing the results by confusion with pressure pain

remains to be discussed. Although, as pointed out by Head and Sherren,[6] deep sensibility may be evoked when testing for touch with a stiff roll of wool, this objection is not valid for determining prick pain within certain limits. A sharp needle was used by Head and Sherren in their early clinical investigation, care being taken to differentiate between sense of deep pressure and true pain. Boring [7] says: "In determining the pain threshold it was especially necessary not to exceed pressures of 6 gm. Although at high intensities of stimulus the introspective difficulty of abstracting from pressure was less with pain than with cutaneous pressure, the greater intensities frequently drew blood and therefore were abandoned." As in Boring's work it was necessary to examine a small area of skin repeatedly and at very short intervals for all forms of sensation, his objection is valid. On the other hand, with the World War cases under consideration, it was necessary only to examine sense of prick pain in areas of overlap and not to confuse this pain with pressure pain. In these cases pain was never found to result from 35 gm. of pressure with a blunt object, and since care was taken to obtain from the patient responses only to pain from prick of a sharp point, it is believed that pressure of even 35 gm. is permissible to map out the overlap of sense of prick pain. No exact measurements of threshold to prick pain were made and in the majority of cases pressure did not exceed 30 gm.

EXCLUSIVE NERVE SUPPLY

Recognizing that, following section of a mixed nerve, the loss to prick pain occupies an area much smaller than the loss to touch, it first was necessary to ascertain the smallest area which is insensitive to pin prick following section of various nerves. This would indicate the limits of any possible overlap.

Although only a small portion of the area insensitive to touch is quite insensitive to pin prick, diminution of pain sense is present in a large part of the area insensitive to touch, and if graduated degrees of pressure be employed, concentric rings of analgesia are demonstrated. However, we are concerned not with the question of whether any hypalgesia is present, but whether any portion of the skin is at all sensitive to pain, provided this pain be due to superficial sensibility. If a part of the skin is sensitive to pain, when a nerve is divided, this sensation must be derived from some source other than this nerve.

To delineate the area exclusively supplied with pain sense by a given nerve one of two conditions must be present: First, the presence of pain sense having been demonstrated within the area of a nerve's supposed anastomic supply, that nerve is found at operation to be divided, and the ends separated. Second, the nerve having been seen to be divided, presence of pain sense is demonstrated in its distribution within the length of time given for the return of protopathic sensibility (Head, Rivers, and Sherren, 43 days). In the cases under the second condition 28 days was the limit, with the exception of the radial nerve, in which the limit was 37 days.

The relatively small number of cases studied does not warrant an attempt to outline the exclusive supply of peripheral nerves to both epicritic and protopathic sensibilities. Suffice it to say that the results as to the nerves in the

hand are in general accord with Stopford,[8] who found in the ulnar nerve some variation from the accepted area of epicritic sense in 20 per cent of the cases and in the median nerve in 38 per cent. In three cases of median nerve section anesthesia was present over the dorsal surface of the distal phalanx of the thumb.

FIG. 127.—Sensory changes in ulnar nerve lesions: Diagonal lines, anesthetic to touch; black lines, loss of prick pain and touch sense; continuous line, borders of loss of temperature sense. The same scheme of charting is followed in all of the diagrams. Where duplication of letters occurs, the first is preoperative and the second postoperative sensory chart

In ulnar-nerve lesions superimposing the outlines of complete analgesia, in the cases shown in Figure 127, the smallest area of analgesia was found to occupy the palmar and dorsal surfaces of the little finger, extending over the dorsal surface of the hand in a triangular area over the fifth metacarpal bone to one-third of its length (fig. 128). The area included between the borders

of the accepted supply of the ulnar nerve and the borders of this analgesia represents the possibly supply of overlapping nerves to pain sense.

The inner border of the smallest area of exclusive supply to pain of the median nerve was obtained in the same way from cases in which the median nerve was subsequently found to be divided (fig. 129, *g, h, i, j*). The outer border was obtained from these cases and in addition from cases of combined ulnar and median lesions which at operation were likewise found to be anatomic divisions, with the ends separated (fig. 129, *a, b, c, d, e, f, k*). The exclusive supply of the median nerve to pain sense was found to occupy the dorsal and palmar surfaces of the distal phalanges of the index and middle fingers, the ulnar half of the palmar surface of the second phalanx of the index finger, part of the ulnar portion of the distal half of the second phalanx of the middle finger and the dorsal surface of less than half of the second phalanges of the index and middle fingers. Despite the fact that this small area of total analgesia in median

FIG. 128.—Smallest composite area of analgesia in ulnar nerve lesions

nerve lesions has been recognized,[9] it is necessary at this point to call special attention to this observation as from the study of this nerve much evidence relative to overlap was obtained (fig. 130).

The cases of radial nerve lesions, certified at operation or examined less than 37 days after resection and suture, showed a wide variety of areas of analgesia and in one case no analgesia at all. (Fig. 131, *a* to *m*.)

Although not infrequently recorded, no case of radial nerve lesion was observed which did not show loss of sensation to touch. Of all the peripheral nerves, the radial shows the greatest variation in the areas of loss of sensation to both epicritic and protopathic sensation. This is due to the fact that six nerves are concerned with the sensory supply of the dorsum of the hand; the median, radial, antibrachii, posterior branch of the musculospiral. musculocutaneous, and ulnar.

Stopford [8] emphasizes, as do Head and Sherren,[4] the importance of the musculocutaneous nerve in the supply of the dorsum of the hand, and states

FIG. 129.—Sensory changes in median nerve lesions: G, H, J, radial and median; I, ulnar and median; B, E, ulnar, median, and internal cutaneous; A, C, D, E, ulnar median, and musculocutaneous, K

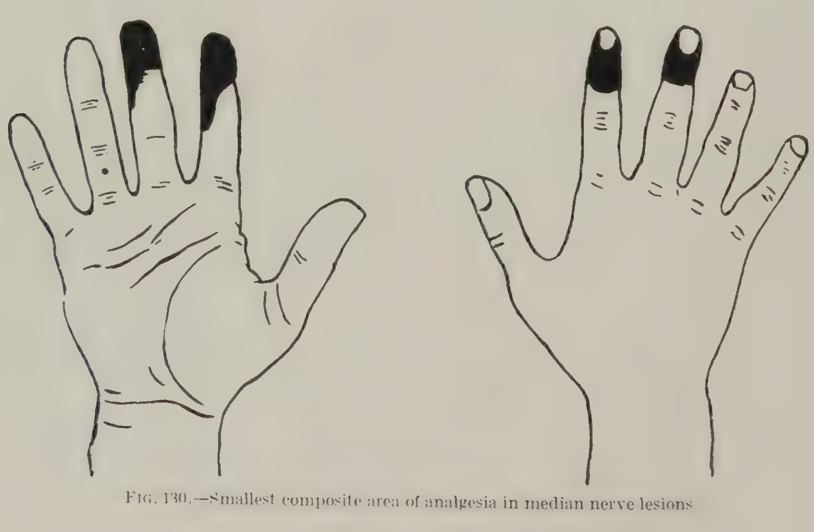

FIG. 130.—Smallest composite area of analgesia in median nerve lesions

that its terminal branches may extend on to the dorsum of the metacarpus, and "it appears that the extent of its distribution varies inversely with that of the radial." Although this may be true, it must not be forgotten that the median nerve must be considered in the supply of sensation to the dorsal area over the distal portion of the metacarpus and the distal portion of the thumb.

FIG. 131.—Sensory changes in radial nerve lesions

One of the reasons for varying reports relative to the sensory loss in radial nerve lesions is the hairy nature of the area of skin under investigation. The early return of hair sensibility frequently is confused with the presence of sense of touch. The skin must be closely shaved in all cases where examination of touch sense is contemplated. No area of skin is exclusively supplied by the radial nerve for prick pain.

FIG. 132.—Sensory changes in external popliteal lesions

The area of exclusive supply of pain of the external popliteal nerve was obtained from certified cases of division and cases examined less than 37 days following resection and suture (fig. 132, *a* to *h*). The area consists of a narrow band extending from a point a little above the junction of the lower and middle one-third of the outer surface of the leg, diagonally across the dorsum of the foot to a point over the middle of the metatarsal bone of the great toe. It is interrupted at the junction of its lower and middle one-third by an area which is sensitive to pin prick. The area is due to the overlap on one side of the internal saphenous nerve and, on the other side, the internal popliteal nerve. Although a number of cases showing such an interruption in the band of analgesia have been observed, they have not fulfilled the requirements demanded in estimating exclusive supply. One case, Figure 132, *e*, showed this type of interruption of the band of analgesia 27 days after resection and suture.

FIG. 133.—Smallest composite area of analgesia in external popliteal lesions

Another case which was examined 53 days after resection and suture is shown in Figure 132, *d*, but was not used in estimating the isolated supply. The external popliteal nerve has a surprisingly small exclusive area of pain sense (fig. 133).

The area of the sciatic nerve was obtained from cases certified to be anatomic divisions, Figure 134, *a* to *f*. This area is illustrated in Figure 135 and need not be described.

Inasmuch as the results above illustrated represent the smallest area of exclusive supply of various nerves for pain, it is necessary to define to what

FIG. 134.—Sensory changes in sciatic nerve lesions

extent they may be used in formulating our ideas relative to nerve overlap. It is recognized that in some instances such small areas may be present only when we are dealing with the group of 25 per cent of cases showing unusual distribution of sensory nerves. These areas are used, therefore, only in establishing a certain limit beyond which it is not permitted to go in interpreting return of sensation to pain as a sign of nerve regeneration. Any return of sense of pain in regions without these borders may be due to unusual nerve distribution or sensory overlap, and represents possible areas of overlap. It will be found that the areas of overlap, described below, are not as extensive as these areas would permit us to assume were we to use exclusive pain sensibility as an indication of the borders of overlap.

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NERVE OVERLAP

The return of sensibility to pin prick, which takes place before the return of sensibility to touch, occurs in regions which occupy the areas of nerve overlap, and this return of sensibility to pin prick can not be interpreted as a sign of nerve regeneration.

This view is supported by the facts that no return of sensibility to pain was found when sensibility to touch had not returned, except in an area of overlap; that when a nerve is divided and at the same time one or more adjacent nerves are divided sensation to pin prick does not return in the area of the overlap of these nerves even many months following the injury; that when a nerve adjacent to one which is severed and which supplies an area of overlap to that nerve is sectioned, the preexisting sensibility to pin prick in the overlap area is lost; that when sensibility to pin prick is present within the anatomic sensory distribution of a severed nerve resection and sature has no effect on the general outline of this area of sensibility.

FIG. 135.—Smallest composite area of analgesia in sciatic nerve lesions

Within two weeks after the occurrence of a peripheral-nerve lesion the area of analgesia usually nearly coincides with the area of anesthesia. Some cases showed an intermediate zone or a shrinkage of the analgesic area within 15 days. In from 30 to 100 days the majority of cases showed the presence of a shrinkage to an extent which was later identified with overlap. It is probable that the cases would have shown the same extent of shrinkage in less than 100 days, but conditions were such that in these cases the first record available was obtained 100 days after the injury. Certainly the majority of cases showed the shrinkage to be well established under 50 days. Some months after the injury had been received the shrinkage was present and the remaining area of analgesia has been described above as the exclusive sensory supply for pain sense in various peripheral nerves.

The shrinkage of the analgesic area can be due to but two conditions: Nerve regeneration, or the assumption of function by adjacent nerves. If any overlapping of peripheral nerves is possible, it becomes necessary to define the extent of this overlap before any return of sensation can be interpreted as a sign of nerve regeneration. So far as it can be ascertained, no evidence has ever been adduced to show that overlapping nerves functionate

immediately following the injury of an adjacent nerve. Neither have the laws of dual innervation been clearly defined. Until this is accomplished, it is illogical to infer that return of sensation in the area of an overlapping nerve is a sign of nerve regeneration and is not caused by the functioning of this overlapping nerve. If the shrinkage of the area insensitive to pin prick responsible for the increase in size of the intermediate zone be a sign of nerve regeneration and not a result of overlap, it should occur whether the adjacent nerves be intact or not. This, however, is not the case, as will be shown. In other words, if certain areas of skin become sensitive to pain or are found sensitive to pain following section of a given nerve, and the condition is due to nerve regeneration, then section of the adjacent nerve would have no effect on the appearance of this sensibility.

FIG. 136.—Sensory changes in combined lesions of the ulnar, median, and internal cutaneous nerves

SECTION OF NERVES

Section of Adjacent Nerves

Although in isolated lesions of the ulnar nerve sensibility to pain is frequently seen on the ulnar half of the ring finger, this is never observed when the median nerve is divided at the same time (fig. 136, *a*, *f*). Although isolated lesions of the ulnar and of the internal cutaneous nerves always show that the distal end of the analgesia resulting from a lesion of the internal cutaneous and the proximal end of the analgesia resulting from a lesion of the ulnar, do not

meet, no instance is found in combined lesions of the ulnar, median, and internal cutaneous nerves where an area between the borders of the analgesia of the internal cutaneous and ulnar nerves is sensitive to pain (fig. 136, *b*, *c*, *d*, *e*, *h*, *i*, *j*).

When the ulnar, radial, and median nerves are divided, a year may follow their division and no shrinkage of analgesia be found on the palmar or dorsal surface of the hand except on the proximal portion of the analgesia where the musculocutaneous and the antibrachii posterior areas adjoin the analgesic area (fig. 137, *a*, *b*, *d*). When a radial lesion is combined with a median, analgesia is always present on the radial part of the palm. When a median lesion or a radial lesion alone is present, this part of the palm is usually sensitive to pin prick (fig. 137, *d*, *e*, *f*, *g*).

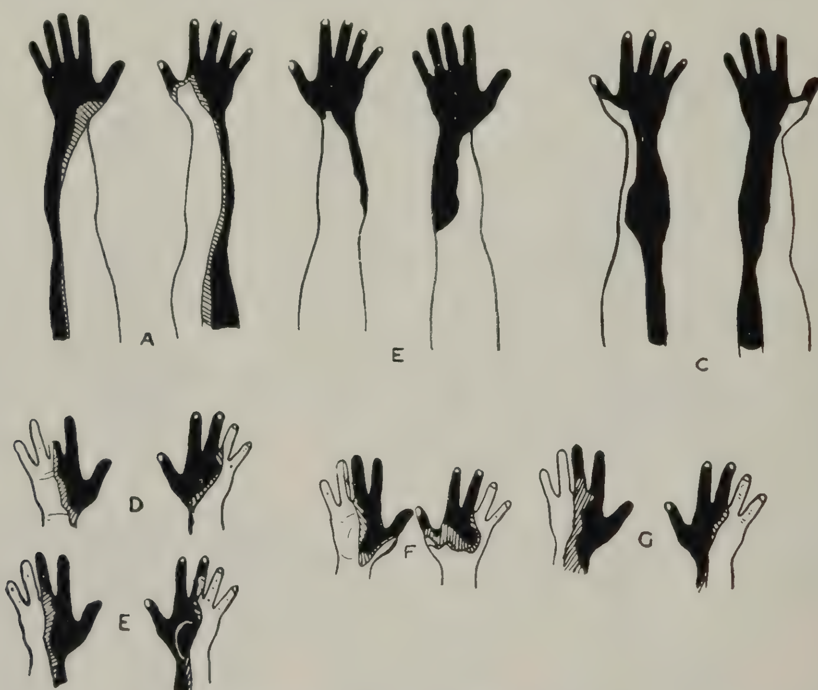

Fig. 137.—Sensory changes in combined lesions of the ulnar, radial, and median nerves, A, B, C, and of the median and radial, D, E, F, G

Isolated lesions of the external popliteal nerve (which corresponds closely to the fifth lumbar root) may show only a small area of analgesia, but when the internal popliteal as well as the external popliteal is severed, there is never found any shrinkage of analgesia or reappearance of sensibility to prick pain in the zone where the supply of the external popliteal meets that of the internal popliteal (fig. 138, *a* to *g*).

It can be definitely stated that when nerves supplying adjoining areas are severed, sensation to pain is at no time present in the border areas where it is uniformly observed when either nerve is divided alone. Inasmuch as a large number of the cases observed had resections and sutures performed at least three months prior to the last examination, it may be stated likewise that no

sensation to pain returns in such areas in the time given for the beginning of regeneration of protopathic sensibility.

Effect of Section of an Overlapping Nerve

When return to sensibility to pain or presence of sensibility to pain is found in the area of overlap of an adjacent nerve, analgesia will result if this nerve is severed. This is well illustrated in the case shown in Figure 129, *g*, page 924. This patient had a partial ulnar lesion combined with a complete section of the median. Prick pain was preserved in the radial portion of the

Fig. 138.—Sensory changes in combined lesions of internal and external popliteal portions of sciatic nerve

palm and the index finger. When at operation the superficial radial nerve was resected for use as a cable transplant, this part of the palm became analgesic (fig. 137, *e*).

Effects of Resection and Suture on Existing Overlap

Following resection and suture when sensibility to pain is present in an area of overlap, although some change in the outline of this area occurs, in general the area remains the same. At times the borders show some increase in analgesia; much more frequently they show a shrinkage of the analgesia. Slight changes in the borders of an area of analgesia can not be used in arriving

at a hard and fast conclusion. Frequently these borders change in an astonishing manner for pain produced by higher degrees of pressure by a sharp point not sufficient to produce pressure pain.

The laws governing dual innervation have not been clearly ascertained. What effect, if any, the handling of nerves or freshening of their ends may have on inhibition is unknown. Another fact in support of the statement that return of sensation in an area of possible overlap can not be ascribed to the regeneration of a nerve is that this area is not generally changed by resection and suture of a severed nerve.

FIG. 139.—Sensory changes before and after resection and suture of the ulnar, median and ulnar, and median nerves

The conditions necessary to study profitably the effect of resection and suture of nerves on return of sensibility to pain are: First, that the nerve ends be separated, and, second, that the examination subsequent to the operation be made within the period of time ascribed to the return of protopathic sense. Some difficulty is encountered in meeting the second condition inasmuch as frequently the wide separation of the ends of the nerves makes it necessary to place the extremity in a position which will permit approximation, and to fix it in such a position by means of a case. This often prevents an examination before six weeks have elapsed. None of the cases under consideration were examined later than 50 days after operation, one in less than 15 days. Although some objection may be made to the cases examined over 45 days after operation on the grounds of beginning return of protopathic sense due to regeneration,

the similarity of the areas unaffected by operation in cases examined under 45 days and those between 45 and 50, coupled with the facts that the ends of the nerves were separated in all of these cases, makes it reasonable to admit them into the group.

To describe again the areas sensitive to pin prick in the lesions examined, or to attempt by description to show the sensory changes following operation, is needless. They are clearly indicated by Figures 139 and 140. It is sufficient to state that the following nerves were studied: Ulnar, examined 42 days after operation (fig. 139 *a*); median, 8 days after operation (fig. 139 *f*); ulnar and median, 45, 36, 40, 46, 48, and 14 days after operation (fig. 139, *b*, *c*, *d*, *e*, *g*, *h*); external popliteal, 48, 36, 20, and 26 days after operation (fig. 140 *a*, *b*, *c*, *d*); sciatic, 50 and 36 days after operation (fig. 140 *f*, *h*).

FIG. 140.—Sensory changes before and after resection of external popliteal and sciatic nerves

RESIDUAL SENSIBILITY

If we assume the relatively early return of sensibility to pin prick to be due to overlap it becomes possible by the method of residual sensibility to outline the borders of overlap of the various peripheral nerves.

The method of residual sensibility is based on the assumption that following section of a given nerve, the area of skin, in its anatomic distribution in which sensation remains, is subserved by the intact adjoining nerves distributed to that area. For example, four nerves supply the palmar surface of the hand: The ulnar, median, musculocutaneous, and radial. If two—the ulnar and

median—are severed, what sensibility remains is subserved by the musculocutaneous and radial. If then the borders of the musculocutaneous be determined, that which remains is radial.

In employing this method certain precautions must be observed. For example, we can not take the outer border of the analgesia on the dorsal surface of the hand in an ulnar section to be any part of the border of the overlap of the median unless we may observe the effect of a combined ulnar and musculospiral so that the overlap of the latter nerve be not included. Similarly, we can not outline the border of the overlap of the median on to the radial unless

FIG. 141.—Sensory changes in lesions of median, internal cutaneous, combined median and radial nerves, B, G, M, from which the residual sensibility of the ulnar nerve was obtained; and of the ulnar and internal cutaneous, radial, combined radial and median nerves, H, J, M, from which the residual sensibility of the median nerve was obtained

we have had a combined lesion of the ulnar and radial to indicate the distribution of the ulnar; or the overlap of the radial to the median on the palm unless we have had a combined median and musculocutaneous lesion, or the overlap of the internal popliteal to the external popliteal unless we have had a combined lesion of the external popliteal with the internal saphenous. The necessity for these combinations reduces the number of cases available for conclusions to a very few. As a result the areas of overlap as outlined probably were smaller than the real overlap. However, the extent of overlap was sufficiently large to prove that it is within such an area that return of sensibility to pin prick occurs soon after injury of peripheral nerves.

It is hardly necessary to state that the cases studied must have nerves recently resected or be examined prior to an operation which reveals the ends of the nerves separated.

In illustrating the areas of overlap the space bewteen the borders of the overlapping to adjacent nerves has been blocked out with black. The black area therefore represents the total supply to pain of the various nerves studied. The area of actual overlap would be that part of the total sensory supply to pain which extends beyond the accepted sensory limit of the adjacent nerves. The restrictions of the methods necessary to obtain these areas are responsible for an indicated area of total supply, which in some instances is smaller than is actually present, as may be seen in the case of the outer border of the ulnar on the dorsal surface of the hand and the inner border of the external popliteal on the back of the leg (figs. 143, p. 936, and 147, p. 938).

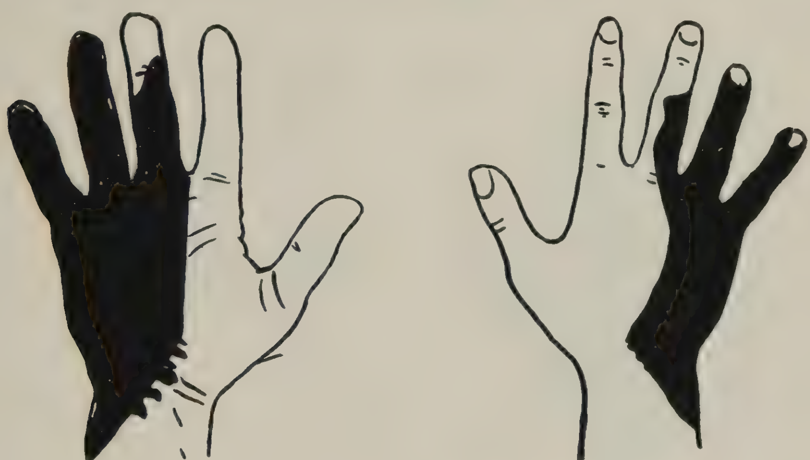

FIG. 142.—Residual sensibility to prick pain of the ulnar nerve

The area of total supply to pain of the ulnar nerve was obtained by the method of residual sensibility from a median lesion, an internal cutaneous lesion, and a combined median and radial (fig. 141, *b*, *g*, *m*). It occupies the ulnar portion of the palm to a line which is a continuation of the ulnar border of the abducted index finger, the palmar surface of the fingers except the terminal phalanx and one-third of the ulnar part of the second phalanx of the middle finger. On the dorsal surface it occupies the ring, little, and more than the ulnar half of the proximal, one and a half phalanges of the middle finger, and the dorsum of the hand to the radial border of the fourth metacarpal bone, ending proximally 1 inch above the wrist (fig. 142).

The area of the median nerve was obtained from an ulnar and internal cutaneous lesion, a radial, a combined radial and median lesion, and cases of combined radial and ulnar lesions (fig. 141, *h*, *j*, *m*). The inner border on the palmar surface was obtained by the method of residual sensibility from an ulnar and internal cutaneous lesion. As to the dorsal surface it was necessary to employ another method, as the cases of combined ulnar and radial lesions were too recent to have had return of prick pain due to overlap. The border

of overlap of the musculocutaneous to the radial was obtained by means of residual sensibility in a case of combined radial and median lesion. Inasmuch as the radial has no isolated supply to prick pain, this border separates the musculocutaneous from the median overlap. Therefore, this border was used as the proximal border of the median overlap to the radial nerve, especially in such cases as showed an area of analgesia between the areas of overlap of the median and musculocutaneous nerves (fig. 141). Part of the inner border of the overlap on the dorsum of the hand is hypothetical and shown as a rough border (fig. 143).

The total supply of the musculospiral nerve was obtained from cases of combined ulnar and median nerve lesions, a case of combined ulnar, median, and musculocutaneous lesions and a case of combined ulnar and internal cutaneous lesions (fig. 141, *a, d, e, f, h, i, k, l, m, n*). An overlap onto the palm was found to an extent heretofore undescribed. In median nerve lesions the sensibility

FIG. 143.—Residual sensibility to prick pain of the median nerve

to pain in the palm has frequently been ascribed to ulnar overlap. But Athanassio-Bénisty [9] recognized the importance of the musculospiral and the musculocutaneous nerves in this condition.

The area of overlap on the palm of the musculospiral nerve extends over the radial part of one and a half phalanges of the index finger, the radial part of the proximal phalanx of the middle finger, and the web between the middle and ring fingers, all of that part of the hand external to a line continuous with the radial border of the middle finger. Internally, it extends from the middle of this line to the middle of the base of the first phalanx of the ring finger and proximally to the middle of the outer surface of the wrist, from which point the border extends in a line to a point 1 inch proximal to the base of the metacarpal bone of the thumb on the radial border of the wrist. This area occupies the entire dorsal surface of the hand with the exception of a strip one-half the width of the little finger on the ulnar border, the little finger, the distal two phalanges of the ring finger, most of the distal two phalanges of the middle

finger and a little more than the distal phalanx of the index finger. The area on the forearm need not be described (fig. 144).

The inner border of the pain area of the musculocutaneous nerve on the anterior surface of the forearm was obtained from the residual sensibility following section of the internal cutaneous nerve; the inner border on the dorsal surface of the forearm, from a musculospiral division. The distal border on the palm was obtained from radial lesions, a combined radial and median lesion, and from lines obtained in combined ulnar and median lesions where an area of analgesia existed between the areas of overlap of the musculospiral and the musculocutaneous (fig. 141, *e*, *f*, *k*). On the dorsal surface of the hand combined sections of ulnar, radial, and median and a case of combined radial and median

FIG. 144.—Residual sensibility to prick pain of the musculospiral nerve

FIG. 145.—Residual sensibility to prick pain of the musculocutaneous nerve

were employed (fig. 137, *a*, *b*, *e*, *f*; fig. 141, *m*, *h*, *j*). The area of total sensory supply to pain of this nerve can be better appreciated by viewing the illustration than by description (fig. 145). The proximal limits of both the musculocutaneous and musculospiral nerves are hypothetical.

Fortunately two cases were obtained from which the overlap of the internal and external popliteal nerves could be observed according to the method of residual sensation. One was the case in which the internal saphenous and internal popliteal nerves were injected with alcohol for causalgia, producing anesthesia, the residual sensibility about which permitted the outlining of the total supply for pain of the external popliteal nerve (fig. 146, *f*). The upper border of this area is hypothetical and merges on the outer surface with the external cutaneous, on the posterior surface with the small sciatic, and on the inner side with the obturator nerve.

The overlap on the sole seen in Figure 147, *b*, is probably smaller than that which actually exists, as may be seen from the presence of sensibility to pain in the blank area of the sole in a case of complete interruption of the internal

FIG. 146.—Sensory changes of combined lesions of internal saphenous and internal popliteal nerves, F; small sciatic, external popliteal and internal saphenous and sciatic nerve lesions from which the residual sensibility of the external and internal popliteal nerves was obtained

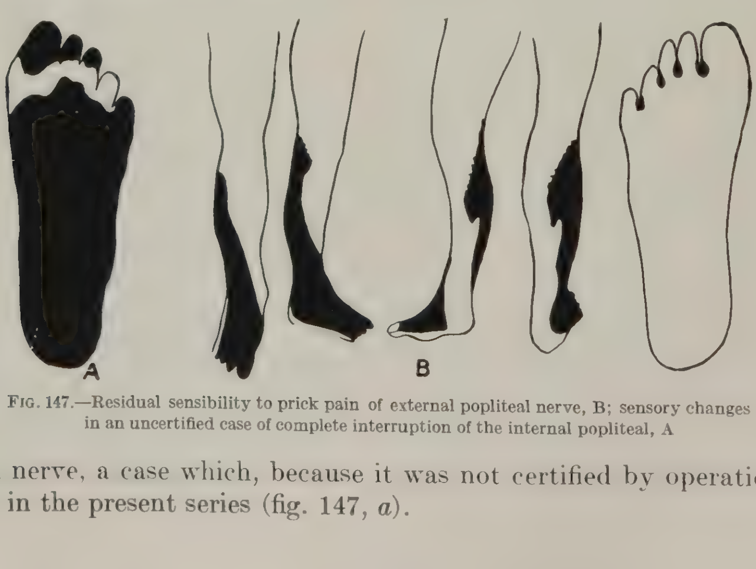

FIG. 147.—Residual sensibility to prick pain of external popliteal nerve, B; sensory changes in an uncertified case of complete interruption of the internal popliteal, A

popliteal nerve, a case which, because it was not certified by operation, is not included in the present series (fig. 147, *a*).

The area of total supply for pain of the internal popliteal nerve was obtained from the residual sensibility in a case of a combined lesion of the small sciatic, the internal saphenous, and the external popliteal nerves, and a case of

FIG. 148.—Residual sensibility to prick pain of the internal popliteal nerve

external popliteal section (fig. 146, *d*, *e*). The upper border of this area is hypothetical and merges with the borders of the small sciatic and obturator nerves (fig. 148).

FIG. 149.—Residual sensibility to prick pain of internal saphenous nerve

The area of total pain supply of the internal saphenous nerve was obtained from the residual sensibility of a combined lesion of the small and great sciatic and cases of sciatic section (fig. 146, *a*, *b*, *d*). The upper border here is likewise hypothetical, merging with the borders of the anterior crural, the external cutaneous, and the obturator nerves (fig. 149).

CONCLUSIONS

1. The area of prick pain supplied exclusively by an individual nerve is far less than the accepted sensory distribution of that nerve.

2. The area between the border of exclusive supply of prick pain of an individual nerve and the border of its accepted sensory supply constitutes the area of algesic nerve overlap.

3. When nerves serving adjacent areas are severed, sensibility to prick pain between these areas is not present after injury, nor does it return before the sense of touch.

4. When a region in the area of sensory distribution of a severed peripheral nerve is sensitive to prick pain, and this region is adjacent to another nerve area, if this second nerve be severed, complete analgesia results in the previous sensitive region.

5. When sensibility to prick pain is present or returns in the area of possible overlap on to the sensory distribution of a severed nerve, subsequent resection and suture of this nerve does not change the general extent of this sensitive area, although the borders may at times be slightly enlarged or diminished; that is, the pain sense returned or present before the operation was not due to partial regeneration.

6. The laws governing the assumption of function by nerves adjacent to a severed nerve are unknown.

7. Handling and resection and suture of previously divided nerves changes the condition governing the function of overlapping nerves, often initiating greater function.

8. Evidence of the assumption of function by nerves adjacent to a severed nerve is not present immediately following the nerve injury, but gradually shows itself at a later date.

9. The early return of sense of prick pain before the return of sense of touch is not due to temporal dissociation of epicritic and protopathic sensibilities, but is due to the assumption of function by adjacent overlapping nerves.

10. The areas of overlap may be determined with fair accuracy and the early return of sense of prick pain in those areas can not be interpreted as a sign of regeneration of the divided nerve.

11. The changes in prick pain following division of a single nerve are not a safe basis for conclusions regarding regeneration of that nerve.

12. Only when a group of nerves is divided at the same time can the studies of sensation be used in the interpretation of regeneration of these nerves. Under these conditions only that part of the analgesic area may profitably be studied which is removed from the effect of overlap from adjacent nerves. On the other hand, if return to sensibility to prick pain occurs on the border of an uninjured adjacent nerve, this return to sensibility does not indicate regeneration of a nerve.

13. Return of sensibility to prick pain can be used clinically for the determination of nerve regeneration only when it is accompanied by return of tactile sense or when it occurs outside the area of possible overlap of adjacent nerves.

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CHAPTER X

ELECTRICAL EXAMINATIONS IN THE DIAGNOSIS OF PERIPHERAL NERVE INJURIES

The importance of making a pathological as well as a clinical diagnosis of injuries to the peripheral nerves as a guide to surgical treatment was recognized early in the war, and consequently neurophysiologists concentrated their attention on this field in an effort to discover a means of accomplishing this purpose. Neurologists had been more or less content with determining what nerve was injured, and the site of the lesion. With the tremendous number of nerve injuries due to war wounds, it became imperative to attempt to decide in addition how much the nerve was damaged, as the treatment differed with the degree of injury sustained. Roughly one could separate nerve injuries pathologically into five groups: Contusion of nerve caused by missile passing through tissue near it without striking it; compression by scar tissue in infected wounds with secondary healing; hemorrhage into nerve without cutting fibers but with central neuroma; partial division with formation of lateral neuroma; complete division with formation of neuroma on the proximal end of severed nerve. A corresponding clinical differentiation was sought on the basis of careful motor, sensory, and electrical examinations. Physiologists familiar with the principles and application of electrical currents in diagnosis agreed that by this means such exact pathological information could not as yet be obtained, but felt that it was by developing this method of investigation more than any other that progress might be made.

A considerable mass of experimental and clinical data to serve as a basis for further study was available as a result of the patient work of physiologists and clinicians of the nineteenth century. Galvani,[1] in 1791, by his accidental discovery of the effect of an electrical current on a muscle-nerve preparation, laid the foundation for all the investigation that followed it. DuBois-Reymond,[2] applying the principle of induced currents discovered by Faraday, devised the faradic induction battery, an apparatus which is used to-day practically unchanged. In 1848 he made the important observation that it was not the passage of the galvanic current but the changes in its intensity which caused muscular contraction. In 1849 Duchenne,[3] of Boulogne, introduced electrodiagnosis with the faradic current, and defined the principles which guide its use to-day. Pflüger[4] established the laws which govern the differences in effect of the opening and closing contractions of the galvanic current. Remak,[5] in 1865, stated "in some cases of completely paralyzed muscle and nerve, the strongest induction shocks do not excite muscular contractions, whilst a stronger effect than the norm accompanies the opening and closing of a constant galvanic current." The most outstanding addition to the practical value of electrodiagnosis was made by Erb,[6] physiologist and clinician, who, in 1883, described the reaction

of degeneration (De R) following complete nerve section. In his book are set forth clearly and completely the practical details of electrical examination and in it will be found many of the suggestions and facts rediscovered by later writers. D'Arsonval,[7] near the end of the century, added to the therapeutics of electrical treatment the proper utilization of the heat generated by the galvanic current passing through tissues.

Further contributions to our understanding of the principles underlying electrical degeneration were made preceding and during the years of the war by Sherrington,[8] Lucas,[9] Adrian,[10] Forbes,[11] Lapicque,[12] and numerous others. A large part of this work has as yet no practical application to the clinical problem, but its value is unquestionable. Thus recent work has resulted in establishing the "all or none" principle of nerve response to stimulation; has demonstrated the return of a nerve impulse to its full intensity after passing diminished through an area of decrement produced by localized narcosis; has advanced the conception of the nerve impulse as deriving its energy from the nerve itself, similar to the burning of a fuse once it has been ignited; and has made a tentative separation of the nerve impulse to the muscle into an element maintaining position (static) and a part controlling motion (kinetic). Facts of normal nerve physiology such as these are the background upon which abnormalities can be judged and are therefore of great importance; but it must be confessed that practically they have not brought us measurably nearer to the possibility of making a diagnosis of the pathological condition of an injured nerve.

There have been a few additions to our knowledge of a more practical nature which may safely be attributed to the interest aroused in this subject by the problems of the war. That the cathodal response is always greater than the anodal in stimulating normal nerves and is usually reversed in degenerated nerves has been known for a long time, but the explanation of this phenomenon has only recently been found. The experimental work of Cardot and Laugier[13] and of Bourguignon[14] has shown that the negative pole is always the active one on making the current, and that the electrical current invariably flows from the cathode to the anode. It is clear, therefore, that when the small stimulating electrode is placed in close proximity to the nerve, a greater response from the concentrated stimulus results, while, when the large, distant electrode is the origin of the current, a diffused and weakened stimulus reaches the nerve from it or from the secondary negative pole, which it causes to appear deep in the tissues. Furthermore, if the nerve is degenerated, the concentration of the current from the small active electrode upon it has little effect, while the relatively more greatly diffused current when the opposite polarity is used, due to its diffusion, stimulates the muscle over a wider area, thus accounting for the apparently greater reaction with the positive pole.

Another important point which has recently received more attention is the increased irritability of the paralyzed muscle to direct galvanic stimulation, the quantity of current necessary for contraction being less than for the normal muscle. This statement requires qualification, for it holds true only for a few weeks after the nerve has been injured, and the response is obtained only by

direct stimulation of the muscle at its tendon insertion and not through its nerve. The increase in galvanic irritability is coincident with increased mechanical irritability, or increased ideomuscular reflex, demonstrated by tapping the muscle. It is worth noting in this connection the interesting observations made by Langley [15] that immediately following section of the nerve the paralyzed muscle is in a state of constant fibrillary twitching, during the time when rapid atrophy is taking place. The association of increased electrical and mechanical irritability, the constant fibrillary activity, and the rapid atrophy when the nervous control of the muscle is removed are instructive as illustrating the loss of inhibition brought about by severing the connection between the anterior horn cell and the muscle. Practically it is possible to utilize this increase in irritability in examination and treatment. The use of strong currents causes contraction of healthy muscles, which may be misinterpreted as the contraction of paralyzed muscles or may make it difficult to determine if the muscles which are being tested are responding. The use of the weakest current which will cause contraction in paralyzed muscles will help to eliminate this difficulty, as this intensity of current does not contract healthy muscles.

Finally the importance of the duration of the application of a current necessary to produce a contraction in a normal muscle has been recognized, and the attempt to apply this knowledge to diagnosis has resulted in the addition to the instruments used for electrical examination of the condenser. It has been found that under fixed conditions for every muscle with a normal nerve supply a definite duration of stimulus is necessary for contraction with a minimal current. The slightest injury to the nerve causes an increase in the time required to produce a contraction with this minimal current, and the degree of injury is reflected in the relative increase in time. Adrian [10] has shown that the normal nerve has a "quick mechanism," responding to a very short stimulus, while the muscle deprived of its nerve requires a stimulus much longer, at least one-hundredth of a second. Expressed in figures it may be stated that a normal muscle will respond to electrical stimulus of 100 volts potential applied to its nerve for about one twenty-four-thousandths of a second. After injury to the nerve has taken place, the duration of the stimulus must be increased to from one five-hundredths to one one-hundredth of a second. The average faradic impulse lasts approximately one one-thousandth of a second, and this current therefore soon becomes ineffective as the nerve degenerates.

To provide an instrument which will readily indicate the time necessary to produce a contraction, the condenser as adapted by Sir Lewis Jones,[16] or some modification of it, has been brought into wide use. By using the discharge through a constant resistance of condensers of different capacity charged at the same voltage, a numerical value could be obtained of the duration of current necessary to produce contraction, and this recorded figure was then available as a basis for comparison on subsequent examinations. The value of this addition to our investigating instruments has been differently stated by various users, and widely different opinions have been expressed. It is agreed that it furnishes confirmatory evidence of nerve injury by showing the increased time necessary to produce a muscular response. It has been claimed that it has value in showing in which direction the injury to the nerve is pro-

gressing, a gradual increase in time necessary to produce a response indicating a lesion which is increasing in severity and therefore requiring operation, and a shortening of the time, a tendency to spontaneous cure, contraindicating operative interference. It would thus have its greatest value as a measure of the progress toward recovery in cases of nerve injury where operation was postponed because a degree of function remained.

An effort was made to gain further information about the condition of the nerve by noting the effects of stimulation of nerves exposed at the time of operation. This was accomplished by using specially constructed electrodes of two wires separated by beads and surrounded by glass tubing. Such an electrode can readily be sterilized. By the use of a weak faradic current the exposed nerve was stimulated directly, and if any response was obtained a partial lesion could be recognized and the surgical treatment modified accordingly. The large number of nerves which were exposed by war injuries gave an unusual opportunity to study the internal geography of the nerve by electrical stimulation, and it is regrettable that advantage was not more fully taken of the opportunity, as the knowledge gained is of inestimable value in the intelligent surgery of the peripheral nerves. However, a considerable number of observations were made, and these have supplemented the careful anatomical studies made by A. Stoffel,[17] who was the first to show the great practical value of a knowledge of the internal topography of nerves.

The methods of examination as actually carried out in Army hospitals devoted to treatment of cases of peripheral nerve injuries may have value as a matter of record. The apparatus used was chiefly the Wappler galvanic-faradic plate equipped with a sliding induction coil of the DuBois-Reymond type, milliamperemeter, rheostat, and pole changer, and the modified Lewis Jones condenser. These instruments were connected with the lighting current. Whenever possible patients were examined on return from the physiotherapy department, as the massage of the paralyzed muscles made their response to electrical tests more satisfactory. The room was kept warm enough to prevent chilling of the skin and the electrodes were covered with wet cotton or chamois skin so as to diminish skin resistance as much as possible. When testing with the galvanic, the current was allowed to pass for a while through the muscle before being broken, as suggested by Erb, a better response being thereby obtained. The bipolar method was used practically exclusively, the large indifferent electrode being placed on the sternum or spine and held by the patient, and the small one being manipulated by the examiner. The small electrode was equipped with a spring on the handle to facilitate making and breaking the current. To determine the polarity of the stimulating electrode in case of uncertainty, the ends of the connecting cords were placed in a glass of water, the negative pole being indicated by the ebullition of bubbles. The amount of current necessary to produce contraction was determined on the corresponding muscle of the opposite extremity. The examinations were recorded in terms of the individual observations, rather than in terms of the conclusions to be drawn from them. Where all the muscles supplied by a single nerve were paralyzed, this was recorded as a group; when only part of them were affected, the individual muscles were specified. Observations were

recorded of the following facts: The presence of sensibility to faradic currents in the skin supplied by the nerve to be tested; the response of the muscle to stimulation with the faradic current at the motor point and directly over the body of the muscle; the response to stimulation of the nerve with the galvanic current; the character of the response of the muscle to stimulation directly at its tendon insertion as to speed and strength of response and the relative effectiveness of opposite poles. In some of the clinics the condenser examination was part of the routine. Examinations were made at about monthly intervals and the results charted on a specially devised blank outline.

The conclusions drawn may be here briefly summarized. Loss of skin sensibility to the faradic current in the most distal area of distribution of a nerve, usually associated with a corresponding loss of deep pressure, vibratory, and joint sensibility, was almost regularly found to indicate complete interruption of the nerve. In the few cases observed which seemed to invalidate this conclusion two explanations were considered possible. Unless careful microscopic sections were made of the fibrous tissue which invariably was found in the gap of a severed nerve, one could not be certain that some aberrant fibers carrying sensation were not contained in it. The other possibility, and one which has a correct anatomical basis, is that anastamosis may occur below the site of the lesion between the injured nerve and one running parallel to it. The return of faradic sensibility to the skin was usually the first certain evidence of returning function.

Loss of response to stimulation of the nerve or muscle with faradic current was invariably found with any degree of traumatic injury to the nerve sufficient to cause motor or sensory disturbances. Immediately following injury the motor and sensory loss was usually over a greater area than could be accounted for by the nerve involved. This condition might rapidly disappear or persist. In the latter case the faradic response readily disclosed which muscles were actually deprived of their nerve connections and which were functionally paralyzed. A normal response in all muscles to faradic stimulation, therefore, was considered to eliminate the possibility of peripheral nerve injury, the paralysis being in such case either hysterical or due to involvement of the central rather than the peripheral nervous system. The phenomenon described by Erb, in which faradic stimulation above the site of the lesion gives no response but stimulation of the nerve below or of the muscle produces contraction, must be guarded against. This condition is interpreted as indicating either a functional blocking of the nerve due to compression or an injury so recent that secondary degeneration is not complete. Kraus[18] has called attention to a similar phenomenon on stimulation of the exposed nerve. Return of voluntary motion invariably preceded the return of response to the faradic current.

Stimulation of the injured nerve with the ordinary galvanic current also failed to give a response no matter how mild the lesion, and this method of examination, therefore, tells us nothing about the pathological condition of the nerve. It is in this part of the electrical examination that the condenser was expected to yield information of value, for by increasing the duration of the current a reaction could be obtained when the nerve was not completely

interrupted. The modified Jones condensers used in the Army hospitals were graded to give a discharge at 100-volt potential from 0.01 microfarad to 2 microfarads. Normal muscle gave a response to the shortest of these discharges. Following injury the duration had to be progressively increased as degeneration of the nerve took place. Of course, when division was complete and followed by secondary degeneration, no length of condenser current gave a contraction.

The changes observed by direct stimulation of the paralyzed muscle with the galvanic current were of the greatest value. Uniformly the muscle failed to respond when stimulated over its motor point, but responded with increased rritability when the electrode was applied over the insertion of its tendon, giving the so-called "longitudinal reaction." The response was delayed, wave-like, or creeping in character, and in general the degree of slowness was an indication of the severity of the lesion. Thus the contraction immediately after injury was still quick, but became slower as the nerve degenerated, and the reverse process took place as the nerve gradually regenerated. When muscles remained without treatment for a prolonged period, such fibrosis might take place that very slight or no contraction could be obtained. This condition warranted a poor prognosis. Occasionally stimulation with the galvanic current gave a tetanic contraction. This phenomenon has been recognized for a long time in the literature of the subject, but no explanation is given for it. Since it occurred with all degrees of nerve injury, its occurrence could not be used as a diagnostic criterion.

Finally a reversal of polarity was commonly found associated with a completely interrupted nerve; that is, the contraction obtained with the anodal closing current was greater than the cathodal closing current. While this phenomenon was occasionally observed in normal muscles, no confusion resulted, as other signs of injury to the nerve were always essential to make a diagnosis of nerve injury. It has been stated by some observers that massage will change the polarity of a muscle.

It was assumed, then, that when the application of the faradic current over the sensory distribution of a nerve was not perceived, and the muscles failed to respond to stimulation with this current, when galvanic and condenser current failed to cause contraction, and muscle stimulation with the galvanic current over its tendon insertion showed an increased contraction of a wave-like, creeping character, with reversal of polarity, a diagnosis of complete interruption could almost safely be made. Partial interruption or compression would be indicated correspondingly by fewer of these signs.

In summarizing the work on electrical examinations, the question that naturally arises is, does this method of investigation give sufficiently accurate and valuable data to the surgeon to repay him for the time spent in carrying it out? Conservative opinion seems to be agreed that this question can be answered in the affirmative. Its greatest value, surely, is in the period which follows shortly after the injury, when with complete motor and sensory paralysis a reaction of degeneration would influence the surgeon to early operative interference. It must be confessed that when such a condition remains stationary for six months or longer, an electrical examination is no longer needed to determine the advisability of operation.

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CHAPTER XI

TECHNIQUE OF NERVE SURGERY

INTRODUCTION

In presenting a system of technique on the operative treatment of peripheral nerve lesions, it is assumed that the reader is familiar with the histopathology and pathologic physiology of peripheral nerve tissue when visited with disease or subjected to injury; it is only on the basis of a thorough understanding of the histologic and physiologic principles involved that a rational operative treatment may be founded. Fortunately, these principles, placed upon a sound footing more than two decades ago, have been amply verified by subsequent experimentation and consistently upheld by the innumerable clinical observations afforded by the vast amount of material supplied by the casualties of the World War. The conclusions arrived at by Howell and Huber in 1891, in their many experimental studies of peripheral nerve physiology, degeneration, and regeneration may still serve as a general text for a rational system of procedure in the operative treatment of peripheral nerve lesions.

Probably in no other type of surgery will the end results so emphatically demonstrate the necessity of subserving physiologic principles. It has been generally known that the fibers of one nerve trunk, when anastomosed to the distal segment of another nerve, will regenerate satisfactorily through the adopted nerve; this fact was utilized in hypoglosso-facial anastomosis for the correction of facial paralysis, though the principle governing this procedure was not based upon a complete physiologic appreciation of all the factors involved. This operation demonstrates the principle of anatomic surgery, in which fibers are supplied to the denervated muscles of the tongue by the anastomosing of one nerve into another. The physiologic principle ignored in this type of anastomosis is manifest in the end results, namely, the paralyzed facial muscles, though having regained some motor power, still remain immobile to emotional facial expression, contracting synchronously with lingual movements during mastication or deglutition. While the paralyzed facial muscles were re-innervated, the innervation from a physiologic standpoint was doomed to failure, because the new fibers innervating the facial musculature are hypoglossal fibers, capable of subserving hypoglossal function only—motor function to the tongue—which is in no way correlated to the emotional reactions expressed through the facial musculature. This represents but one type of physiologic transgression in the surgery of nerves.

Most peripheral nerves are both motor and sensory in functions; the motor portion of the nerve trunk, derived through a neuraxon outgrowth from the motor cells in the anterior horns of the spinal cord, carry efferent motor impulses; the sensory portion of the nerve trunk is composed of fibers which carry

sensory or afferent impulses through the posterior horns of the cord. These motor and sensory fibers, though anatomically incorporated within a single nerve trunk, are from a physiologic standpoint totally unrelated; this well-known physiologic fact, when given due consideration, immediately elevates the operation of nerve suture from the domain of anatomic to that of physiologic surgery. The anatomic principle of simply obtaining a satisfactory end-to-end approximation of a divided peripheral nerve, adequate to permit the passage of regenerating fibers, does not suffice in nerve surgery, for it may, from a physiologic standpoint, be very imperfect, in that the motor fibers in regenerating may enter sensory channels leading to sensory terminations, and these motor fibers, not being able to subserve sensory function, would be physiologically lost.

A study of the end results following nerve suture has amply demonstrated that perfect anatomic sutures are frequently attended by only a partial restoration of function, and occasionally by its total absence. At best, the unqualified anatomic principle of nerve suture, without regard to the physiologic differentiation of fibers, can be nothing more than a hit-or-miss method of procedure. If in the approximation of the ends of the divided nerve the surgeon is fortunate enough to approximate motor fibers to the motor channels in the distal segment and sensory fibers to their respective channels, the ultimate results—if regeneration is unimpeded in both nerve and muscle—should be a complete restoration of function. The possibility of a physiologic approximation, if left wholly to chance as in an ungoverned anatomic suture, can be seldom expected, though in the majority of instances some motor fibers will probably (by chance) reach motor channels and regenerate to a motor termination; no doubt many will be lost, and our experience seems to indicate that the regenerating motor and sensory fibers are incapable of selecting their respective physiologic channels. The principle of physiologic approximation resolves itself almost entirely into the prevention of torsion of the nerve trunk during suture; the most important factor involved in the technique of nerve surgery depends upon our ability to prevent or correct this unfortunate incident. While end-to-end approximation is absolutely essential to neuraxon regeneration, physiologic approximation is indispensable to the restoration of function.

An adequate conception of physiologic principles will immediately enable the surgeon to disregard many of the older operative procedures of nerve anastomosis, more or less brilliant from a purely anatomic standpoint, but absolutely futile when considered in the light of our present knowledge. An appreciation of the fact that each fiber within a nerve trunk has to a greater or lesser degree some functional individuality should lead the surgeon to a realization that, though it is within his power to change the anatomic course of these fibers, their physiologic attributes remain unchanged; at best, his most painstaking and careful operative manipulation, however ingenious from an anatomic standpoint, loses in functional value in direct proportion to the perversion of the original physiologic pattern. Satisfactory end results in nerve surgery depend primarily upon a full appreciation of physiologic function and our ability to conserve the anatomic characteristics compatible with the normal expression of that function.

THE GENERAL TECHNIQUE

ANATOMIC REQUIREMENTS

Primarily it is essential that the operator have that practical working knowledge of peripheral nerve anatomy which is acquired and maintained only by frequent recourse to the dissecting room. It is particularly important that he be familiar not only with the general course and relationship of nerve trunks, but also the origin and distribution of the various branches as they arise; it is not only essential that these branches be preserved in dissection, but they must also be exposed and accurately identified in order to determine, by their intraneural position, the intraneural topography of the nerve trunk. While no dogmatic rule may be laid down regarding the point of separation—superficial origin—of branches from the parent trunk, their intraneural course, as a rule, is sufficiently constant to permit a fair degree of accuracy in topographical identification. It is usually necessary that the particular branch under consideration be liberated for a short distance up the nerve trunk, in order that its exact intraneural position be accurately determined. Occasionally a motor branch may have its superficial origin from the sensory side of the nerve trunk, but its deep intraneural position will usually be found to be in that sector of the nerve trunk which contains the motor bundles. The exposure and identification of motor and sensory branches, arising from a peripheral nerve, is of exceedingly great value in topographical localization, as their intraneural localization will nearly always indicate that portion of the nerve trunk which subserves their respective function, either motor or sensory.

PREPARATION OF AN EXTREMITY FOR OPERATION

It is important in nerve operations that the skin of the entire extremity be sterilized from a point some distance above the proposed incision. The necessity of sterilizing the peripheral portion of the extremity is due to the fact that manipulation of the entire limb is frequently necessary during an operation; the observation of the entire limb during electrical stimulation of the nerve is essential to determine the action of individual muscles. This is particularly important in the hand. Occasionally a sterile rubber glove may be used to cover the hand of the patient, when adequate sterilization is doubtful. The glove usually will permit observation of muscle action. The draping of an extremity should always be arranged in such a manner as will facilitate observation and manipulation without contamination; the surgeon should personally direct the placing of protective sheets and towels with this object in view.

Position

The position of an extremity, for operation upon one of its principal nerves, should be planned with as much forethought as might be given to any other step of the operation; the surgeon should endeavor, by the effective placing of sand bags, to maintain the extremity in a position conducive to the comfort of the patient as well as to his own convenience. A third assistant, or a sterile nurse with specific instructions, should be retained to maintain the extremity in the desired position of flexion, when flexion-relaxation is utilized in the correction of continuity defects.

ANESTHESIA

Local anesthesia, in the writer's experience, has supplanted all other types of anesthesia for peripheral nerve work. Its proper use is attended with complete analgesia, with the retention of motor function. It permits the use of the electro-anatomic method of funicular identification; it greatly diminishes the oozing encountered in scar tissue dissections; and avoids the disagreeable complications attending inhalation anesthesia.

The following technique is used in producing local anesthesia: A 1 per cent solution of novocaine or procaine is used, to each ounce of which 15 minims of a fresh 1:1,000 adrenalin chloride solution has been added. The line of proposed skin incision is carefully infiltrated, producing a continuous line of intradermal wheals. The needle is now passed into the subcutaneous tissue for a depth of 1½ cm., where 1 c.c. of the solution is injected; the needle is then directed deeper and a second injection is made. Without withdrawing the needle, which should be sufficiently long to reach the nerve, these injections are made at an increasing depth until the tissues surrounding the nerve have been reached. These subcutaneous injections are made about 2 or 2½ cm. apart, along the entire line of the proposed incision. At each injection, in deep infiltration, particularly in the region of a large vessel, the piston of the syringe should be slightly withdrawn before any of the solution is injected, to determine the possibility of an intravascular penetration; if blood is aspirated the needle should be redirected. It is usually neither necessary nor desirable to inject the nerve until it is ready for section, unless pain is experienced. After the field has been thoroughly infiltrated, pressure is used for a few minutes to promote the diffusion of the solution through the surrounding tissues. If it be necessary to carry a dissection to the surface of a bone, its periosteum should be infiltrated. When the incision and surgical manipulations are confined to the infiltrated areas, they are absolutely painless and frequently bloodless; and, as most peripheral nerve operations are attended with much scar tissue dissection, this bloodless field is highly desirable.

EXPOSURE OF THE NERVE

The importance of long incisions and adequate exposures can not be too greatly emphasized in the surgery of peripheral nerves. It has usually been our experience that a seemingly adequate incision will require lengthening before the operative procedure is completed. This possibility should always be borne in mind during the preparation of the skin and draping of the extremity, for by so doing the surgeon will avoid the risk which attends invasion of parts not adequately prepared.

One of the greatest mistakes a surgeon can make is to attempt the exposure of a nerve in a scar-invaded region; for safety's sake alone, without a consideration of other advantages, the surgeon should make it his invariable rule to expose the nerve above and below the lesion, when the location of the lesion will permit. The nerve, having been exposed in a region where normal anatomic relationships prevail, may then be followed through the scar-invaded area where these anatomic guides have been distorted or lost.

The prevention of scar tissue following nerve operations is of paramount importance; and while it can not be wholly obviated, there is no doubt but that it may be greatly mitigated by a careful operative technique. Scar tissue following surgical intervention is usually the result of tissue trauma, inadequate hemostasis, and infection. Tissue trauma may be reduced to a minimum by careful, clean-cut dissections, confined when possible to normal lines of cleavage. A common source of tissue trauma lies in the use of artery forceps and the ligation of vessels. When it is necessary to clamp a vessel, no more tissue than is absolutely necessary should be crushed to secure the vessel. The habit of crushing and ligating the entire area around a vessel is greatly to be deplored, as it is accompanied by considerable tissue strangulation and subsequent necrosis, inviting infection and scar formation. Blunt and finger dissection, which is so frequently associated with tissue tearing and extensive trauma has no place in the surgery of peripheral nerves. The use of antiseptics, such as iodine, within the wound is to be condemned. It is desirable to cover the skin edges with clamped towels, as complete skin sterilization is often questionable. Parts of the incision which are not receiving immediate attention may be prevented from drying and protected from contamination by cotton pads saturated with warm saline. Scar tissue dissections, which under general anesthesia would be associated with constant oozing, are often rendered bloodless by infiltration anesthesia, and by the time the constricting action of the adrenalin has disappeared clotting has occurred in those oozing points which so often defy ligation. A time-saving procedure in the dissection of neurovascular bundles is preliminary control of the circulation by isolation of the veins below the lesion and the artery above, which structures may be temporarily constricted by tape to control hemorrhage following vascular accidents. Nothing is more deplorable than to see a surgeon blindly attempting to grasp an unseen bleeder in a pool of blood; in nerve surgery such a procedure is fraught with so great a degree of danger to nerve trunks and branches that it is inexcusable, in that it may usually be obviated by using sufficient precaution for vascular control.

DEFECTS IN NERVE CONTINUITY

When a nerve is divided its ends tend to retract in the surrounding loose connective tissue, where they become fixed with the process of healing and the formation of scar tissue, making a defect in nerve continuity. In certain instances a portion of the nerve trunk may be completely destroyed or traumatized to such an extent as to obliterate its recognizable anatomic continuity; more frequently, however, the nerve so suffers from the devastating effect of infection and subsequent scar-tissue proliferation that large sections must be sacrificed before normal-appearing nerve bundles are found in its ends.

Various procedures have been recommended for the correction or filling of nerve defects, many of which have little, if any, physiologic grounds for support. Mechanically, some of the procedures recommended for the filling of defects, such as the interposition of tubes and various other foreign materials, may appear to be very ingeniously conceived, but from a physiologic standpoint they were often so defective that the probability of recovery was actually

minimized by the procedure. To permit nerve regeneration, direct anatomic approximation of the nerve ends must be attained. In certain instances when this is found to be impossible, the use of the autogenous cable graft is justified for filling defects, but at best it seems to promise but a very moderate degree of functional restoration. The interposition of heterogenous nerve grafts has been so universally unsuccessful in clinical experience that their use is to be discouraged. Various procedures, such as nerve implantation into neighboring nerves and the neurotization of paralyzed muscles, have so little to recommend them from a practical standpoint at the present time that they may be dismissed from the category of effective clinical procedures.

The following methods of correcting continuity defects in peripheral nerves are the only ones whose functional end results, in our experience, justify usage: (1) Primary nerve stretching; (2) flexion-relaxation; (3) nerve transposition; (4) stretching with secondary suture (two-stage operation); (5) autogenous cable grafts; (6) viable neuroplastic transplants; (7) bone shortening.

PRIMARY STRETCHING

Primary stretching will overcome many of the lesser defects. It consists of freeing the nerve trunk beyond the area of scar tissue fixation and drawing its ends together by gentle traction. Extensive mobilization of a nerve trunk permits a proportionately greater stretching. It is particularly necessary to freely mobilize the nerve beyond the region of extraneural adhesions, but in doing this, great care should be exercised in avoiding injury to branches.

FLEXION-RELAXATION

The majority of nerve defects may be corrected by taking advantage of the relaxing effect upon a nerve trunk, by flexion of governing joints. The approximation of the nerve ends is made possible, after the nerve is prepared for suture, by flexing the governing joint, in which position it is maintained, after the nerve is approximated, by suitable splints until the wound is healed; after which the mobilizing splints are occasionally changed to permit a gradual extension of the flexed extremity. In our study of end results of nerves under tension or those stretched by the foregoing method, we have not found that this stretching seriously interferes with regeneration; in fact, some of our best end results have been observed in cases where approximation was attainable only under considerable tension. In our early experience, when flexion-relaxation was used in overcoming large defects, we maintained the limb in the position of primary flexion for a period of six weeks; later, however, this period of fixed flexion was reduced to two weeks, after which the gradual extension of the extremity was permitted at the rate of approximately ten degrees every second day.

NERVE TRANSPOSITION

The course of certain nerves in the arm may be made more direct and thereby shortened by transferring them from a dorsal to a more ventral plane. This procedure is commonly used to great advantage in overcoming the more extensive defects.

The ulnar nerve in its normal position behind the internal condyle is not relaxed by flexion of the elbow until it has been transposed to a position anterior to the internal humeral condyle. This procedure not only somewhat shortens its course but also renders it susceptible to flexion-relaxation. The musculospiral nerve is occasionally transposed, being directed from its posterior humeral course to one anterior to the humerus. Large defects in the median often require for their correction a transposition of the nerve from its deep position below the superficial head of the pronator teres to one ventral to this muscle.[a]

In the transposition of nerves it is essential that the operator be familiar with the various branches given off from that portion of the nerve trunk requiring mobilization; these branches must be freed some distance up the nerve trunk by an intraneural dissection to permit mobilization without their avulsion. It is also essential to place topographical markings on both proximal and distal segments of the nerve by means of well placed identification sutures, before the position of these segments has been disturbed and anatomic relationships lost, in mobilization.

STRETCHING, WITH SECONDARY SUTURE (TWO-STAGE OPERATION)

After a divided nerve has been exposed and found to present a defect, the surgeon should determine means of correcting this defect before the neuroma and scar tissue have been excised from the ends of the nerve. If it be found that the defect will not lend itself to correction by one of the foregoing methods, the operator must then resort to the two-stage operation. This consists in extensive mobilization of the nerve trunk after it has been marked with topographical identification sutures, and all possible relaxation has been attained by transposition and flexion-relaxation. The unsectioned nerve ends are drawn together by one or two strong chromic catgut traction sutures, using sufficient tension to permit, if possible, an overlapping of the nerve ends to a point approximating that which will correct the defect, after the scar tissue has been resected; or at least, to obtain as much overapproximation as possible. The wound is now closed, and after one week the extension of the extremity begun, the object being a gradual stretching of the nerve trunk. When this has been accomplished by complete extension of the extremity and the wound is entirely healed so that it is safe for a secondary aseptic invasion, the nerve is again exposed; the neuroma and scar tissue are resected and the freshened ends approximated by again utilizing the assistance of flexion-relaxation. The extremity is splinted in this position for a period of two weeks, after which extension is gradually encouraged. Many of the defects encountered in extensive lesions of nerves have been corrected by a two-stage operation, and only when the nerve defect is of such magnitude as not to be corrected by the above method are we justified in resorting to grafting.

NERVE GRAFTS

From an experimental standpoint, nerve grafting has attracted considerable interest and much has been expected from this procedure; from a clinical stand-

[a] The technique of transposing the above nerves is considered in detail under the surgery of special nerves.

point, however, the end results have been very disappointing. A review of end results in so far as functional restoration is concerned, in 15 cases in which the operations were done by different operators, shows that functional restoration was nil, with the exception of one instance in which there was some return of sensation in a low median graft. (This restoration consisted, after four years, in simply the restoration of a nondiscriminative sensation in the index and middle fingers. All sensation, including touch, pin prick, heat, and cold, were interpreted as tingling—differentiation not being possible.) In the writer's experience, a number of homogenous refrigerator grafts were tried out; in each instance the condition of the wound was favorable and remained so throughout the healing process, though in no case was there any clinical evidence of regeneration. These grafts when subsequently removed showed a total absence, histologically, of nerve fiber regeneration, and the proximal end of the nerve trunk exhibited a secondary neuroma. In most of the above instances it was later found possible to obtain satisfactory end-to-end approximation by the above-described two-stage operation. With increasing experience in dealing with large defects, we found that in most instances it was possible to repair the defect by a two-stage operation, thereby almost entirely eliminating the necessity for grafts. Occasionally, however, defects are found of such magnitude that the only possibility of nerve repair lies in grafting, but as a rule such cases, by virtue of their severity, the extent of tissue destruction and scar tissue formation, promise but little in the way of satisfactory functional restoration. It must be remembered that the experimental work of nerve grafting which has been attended with such satisfactory results has been done in relatively small defects under extremely favorable conditions from a surgical standpoint. Such satisfactory conditions are rarely encountered clinically because of the severity of the original lesion which makes nerve grafting necessary.

Autogenous Cable Grafts

Autogenous cable grafting consists in exposing the ends of both proximal and distal segments of the divided nerve and preparing them for suture. The length of the defect between the nerve ends is measured and the grafts to be inserted are selected from convenient sensory nerves. In the arm the following nerves may be utilized: Radial (sensory portion of the musculospiral), sensory portion of the musculocutaneous, internal cutaneous. In the leg: Sensory portion of the musculocutaneous, tibial, and peroneal recurrent, the sural branches of the peroneal nerve. One or several segments from one or more of the sensory nerves, of sufficient length to fill the defect, are removed and transplanted to fill the gap between the ends of the damaged nerve. These sensory branches are usually so small that several are required in making a cable which will approximate in size the nerve trunk. After a cable graft of sufficient size and length is obtained, it is carefully anastomosed to the ends of the nerve trunk and in this way made to bridge the defect. It is essential to obtain accurate end-to-end approximation between both ends of the nerve trunk and graft. If a defect in a small nerve is being bridged, it may be possible to obtain a sensory graft of approximate size, thereby eliminating the necessity of using

several grafts as a cable. It is particularly important that a favorable bed be found to protect the grafted nerve. The writer, in the removal of a number of unsuccessful grafts, has found them converted into strands of fibrous tissue; in a few instances some regenerating neuraxons were found to have penetrated the proximal end of the implant, but in none had they succeeded in completely traversing the graft.

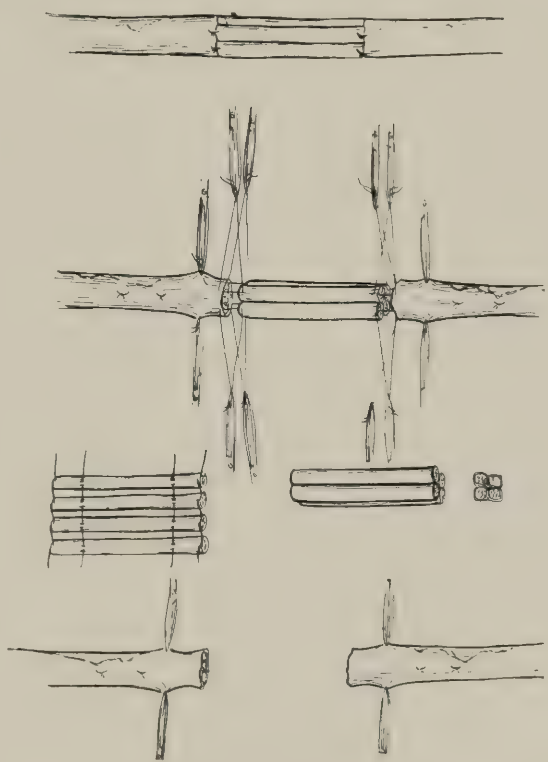

FIG. 150.—Bundle or "cable" graft, using an autosensory nerve for repair of the defect. (Ney. *Annals of Surgery*, 1921)

VIABLE NEUROPLASTIC TRANSPLANTS

In irreparable defects of combined nerve lesions, such as the median and ulnar or the tibial and peroneal portions of the sciatic trunk, the writer, by sacrificing the nerve of lesser importance, devised a method of filling the defect in the more important nerve with a viable transplant. In this procedure, for example, in a combined median and ulnar irreparable defect, the median considered to be the nerve of greater importance, the end of its proximal segment is anastomosed by end-to-end suture to the proximal end of the ulnar nerve—the nerve of lesser importance—permitting the median fibers to regenerate around the loop so formed by the anastomosis and up the ulnar trunk. The ulnar nerve is divided the required distance (length of median defect) above its anastomosis to permit the degeneration of its fibers in that portion of the trunk which subsequently is to be used as a transplant, thereby preparing it to receive the regenerating fibers of the median nerve. The trunk of the sacrificed ulnar nerve remains undisturbed in its original position, to conserve its nutrition during the migration of median fibers through its entire length. Before the transplant is utilized, it is allowed one month for each inch of its length plus one month's grace, to assure regeneration through its entirety. The upper end of the adopted trunk may be placed subcutaneously if desired, where it can be readily palpated and percussed to determine the growth of nerve fibers to its extremity—the presence of regenerated fibers may be readily demonstrated by Tinel's sign, thus assuring the surgeon of the viability of the transplant before it is turned down at the second stage of the operation.

The advantage of the viable neuroplastic transplant is that its nutrition is maintained during neuraxon regeneration, and at the time of use it has, to

all intents and purposes, become a viable part of the nerve trunk, containing intact and viable neuraxons. It then may be united to the distal segment of the nerve with all the advantages of a direct approximation. The writer has restricted its use to the repair of inoperable combined lesions in which he felt justified in sacrificing a permanently disabled neighboring nerve. The possibilities of the viable neuroplastic transplant will probably be extended with experience as it seems at the present time to be our only practical method of filling nerve defects. The results following the use of the viable transplant are comparable to those following direct approximation.

BONE SHORTENING

Bone shortening is occasionally justified for the correction of large nerve defects, though the arm should not be shortened until full advantage is taken of other means to correct the defect. Shortening of the upper extremity does not, of itself, produce serious disability, but obviously such a procedure would not be practical in the lower extremity. Before recourse is taken to bone shortening the two-stage operation of nerve stretching should be tried; if this fails by a few centimeters to correct the defect, humeral shortening to this extent may be practiced to assist the other procedure. When a section is removed from the humerus for the purpose of shortening the extremity to permit coaptation of divided nerves, the resection is usually done in its lower third, care being taken to prevent injury to the musculospiral nerve if the exposure is carried into the middle third. The bone may be divided with a Gigli saw, after which it is dislocated through the incision and a section sufficiently long to correct the defect removed. The ends of the bone are approximated before suturing the nerve, by bone plates or a medullary graft, or by their combination. It is particularly important in approximating the nerve and closing the incisions to prevent unnecessary movement which might disturb the position of the bone or throw undue strain upon the bone plates or graft. The arm should be carefully immobilized with plaster to a body cast which has been applied before the operation, and so maintained for a period of six weeks or until firm bony union has taken place. A window should be made in the cast which will permit inspection of the wound and change of dressings when necessary. The skin is sutured with catgut to prevent the disturbance of suture removal.

ANKYLOSED JOINTS WITH NERVE DEFECTS

Occasionally an ankylosis of the elbow or knee joint will prevent the utilization of flexion-relaxation in overcoming continuity defects in nerves. The advisability of resorting to arthroplasty for the correction of ankylosis in these joints will depend greatly upon the disability resulting from the combined nerve and joint lesion. Much has been said for and against arthroplasty as a practical procedure; many surgeons of experience are in favor of allowing these joints to remain ankylosed, providing their position is useful. The writer is inclined to believe that in many instances very satisfactory results will follow a well-planned and carefully executed arthroplasty; this is particularly true of the elbow, when the ligaments have not been extensively destroyed.

A flail-joint, however, is more disabling than one ankylosed in the position of maximum usefulness. If arthroplasty has made it possible to repair the nerve and restore function in the paralyzed muscles, even though it result in a flail-joint, it has served a useful purpose, for the joint may again be ankylosed in a convenient position.

IRREPARABLE NERVE DEFECTS

The neurologic surgeon, in about 5 per cent of cases, will meet continuity defects in injured nerves of a magnitude so great as to preclude the hope of successful nerve repair. In such instances he must resort to various supplementary procedures which will promise some degree of ultimate functional usefulness in the injured extremity. From a motor standpoint, tendon transplantation frequently offers a fairly satisfactory solution of the problem. In other instances, the immobilization of joints must be resorted to; this procedure is of value in deltoid paralysis, in upper plexus lesions with loss of elbow flexion, and in stabilizing the foot in irreparable lesions of the sciatic nerve. These various supplementary surgical procedures, though ordinarily falling within the realm of orthopedic surgery, should be done, or at least directed, by the neurologic surgeon, who is familiar with the neurologic aspects of the case. This is particularly important in tendon transplantations, which require a thorough knowledge of the existing motor status of each individual muscle utilized in the transplantation, if one is to obtain the most satisfactory functional end results.[b]

TORSION OF THE NERVE TRUNK DURING SUTURE

A most serious eventuality in the repair of nerves is torsion of the nerve trunk during suture. Many surgeons have been content to obtain a satisfactory end-to-end approximation of the divided nerve, but a physiologic appreciation of the functional individuality of the various bundles within the nerve trunk should tend to discourage such a procedure as being manifestly inadequate, for the final results are greatly inferior to those of a technique where due regard is paid to physiologic approximation. There are very few instances in which it is not possible to obtain at least some idea of the topographical anatomy of the nerve trunk before suture, and the surgeon who has not the ability, time, or patience to use the physiologic technique in all its phases is not justified in attempting the repair of peripheral nerves.

There is no evidence at our command, and much to the contrary, to verify the ability of motor and sensory fibers to find their respective physiologic channels during regeneration through the distal segment of a divided nerve trunk. If motor fibers are placed in contact with the sensory channels of the lower segment, these regenerating motor fibers will follow the sensory channels, into which they have been directed, to a sensory termination, and be physiologically lost; it is not possible for motor fibers to subserve the function of sensation, nor are sensory fibers capable of carrying efferent motor impulses

[b] Supplementary procedures applicable to individual nerves are considered in detail under the surgery of special nerves.

to muscles, if, during suture, they should be directed down motor channels. This physiologic misdirection of nerve fibers is probably responsible for much of the defective end results attending the surgery of peripheral nerves; and while our present technique is not sufficiently refined to differentiate accurately the position within the nerve trunk of these respective motor and sensory bundles, it is possible for the surgeon, with a fair degree of accuracy, to maintain the physiologic alignment of the nerve during suture by the use of the following methods: (1) Identification sutures; (2) forceps identification; (3) anatomic or branch identification; (4) electro-anatomic method.

IDENTIFICATION SUTURES

Identification sutures are placed at a corresponding point in both proximal and distal segments of the nerve sheath before the normal position of the nerve has been disturbed by dissection; the purpose of these sutures is to identify a definite circumferential point upon the nerve trunk which will permit, during approximation, a restoration of original anatomic alignment without torsion. It is well that these sutures be placed some distance above and below the lesion where normal anatomic landmarks prevail and where the nerve has not been subjected to torsion through the contraction of scar tissue. This procedure is undoubtedly the simplest and perhaps the most efficacious method of preventing torsion. Two sutures may be placed, one above the other, to assist in more accurate alignment. When the scar tissue is resected from the nerve ends preparatory to suture, these identification markings should be lined up most carefully and the approximation sutures placed in a manner which will maintain this alignment.

FORCEPS IDENTIFICATION

From the standpoint of technique, forceps identification offers certain advantages and may be used in conjunction with identification sutures, or independently. As the nerve trunk is exposed and before it has been completely freed from its bed, the nerve sheath is grasped on each side with very fine mosquito hemostats. These forceps are so placed on both proximal and distal segments that they locate exactly the center of the medial and lateral aspect of the nerve, for the purpose of permitting alignment; they also serve efficiently to stabilize the nerve while it is being sectioned. Unless care is used, the operator may rotate the nerve trunk and produce torsion by alignment of lateral forceps with medially placed forceps, if the forceps used on each side of the nerve trunk are of the same pattern. (To prevent this, the writer identifies both laterally placed forceps by tying a suture to the thumb piece, which will serve for lateral identification in the alignment.)

ANATOMIC OR BRANCH IDENTIFICATION

This may be utilized in many locations to effect satisfactory alignment; it is particularly valuable in secondary sutures, when the surgeon has reason to believe that due regard had not been paid to physiologic alignment during the primary suture; it is also of value in checking up the accuracy of identification sutures.

A careful study of a series of dissections has convinced the writer that both motor and sensory bundles occupy within the nerve trunk a very definite and relatively constant position. While no dogmatic rule may be given as to the position of exit of a nerve branch from the parent trunk, it may be generally stated that if the nerve sheath be opened for a short distance a given branch will invariably be found to originate from a definite position within the nerve trunk. If a motor branch be followed a short distance up the nerve trunk, it will be found to occupy a definite location which indicates the position of the motor bundles in the nerve trunk. The identification of motor branches springing from both segments of the divided nerve, when these branches have received proper intraneural localization, will assist materially in accurately approximating motor segments during suture.

To reiterate, if a motor branch to a given muscle is identified and followed a short distance up the nerve trunk until it has assumed a fixed intraneural position, this position may be definitely regarded as the location of the motor portion of the nerve. It may be termed the motor sector; conversely, the other side of the nerve would be the sensory sector. The utilization of this information serves topographical localization and physiologic identification when other methods, such as identification sutures, are not to be relied upon. With the study of the topographical anatomy of individual nerves, this method of branch identification becomes of increasing value. Obviously, the surgeon who expects to use this method must familiarize himself with the intraneural anatomy of the nerve upon which he contemplates surgical invasion.[c]

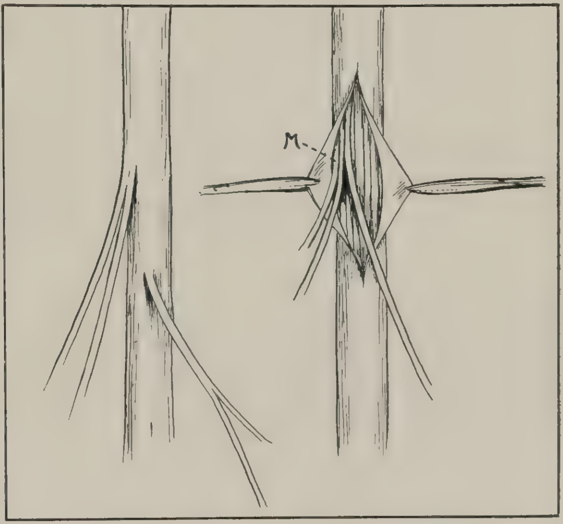

Fig. 151.—Diagram showing the necessity of determining the intraneural location of a given branch. A motor branch may leave the sensory side of a nerve trunk, and intraneural dissection is required to establish its deep origin which represents the motor sector of the trunk; the superficial origin of nerve branches is often misleading and varies considerably

THE ELECTRO-ANATOMIC METHOD

This method presents certain refinements in topographical localization, unattainable by purely anatomic methods. In the lower segment, the motor portion of the nerve trunk is localized by the anatomic or branch identification method as described above; in the upper segment, the sensory side of the nerve trunk is localized by weak faradic stimulation of its various bundles, after the nerve sheath has been opened 2 cm. above the nerve end. The technique of

[c] Under the surgery of special nerves such detailed information as is now available regarding the method of anatomic identification is considered.

this procedure consists in exposing the nerve by infiltration anesthesia, without injection of the nerve trunk proper. (See technique of local anesthesia, p. 952). Two centimeters above the scar invaded end, the nerve sheath is opened longitudinally and its pearly white bundles exposed; two or three of these bundles are isolated from intraneural connective tissue by gently inserting and spreading the blades of fine-pointed iris scissors parallel with the course of the bundles. A single bundle is then lifted upon a fine glass hook and subjected to very gentle faradic stimulation with a fine needle-pointed bipolar electrode. If a sensory bundle be stimulated, the patient will complain of a tingling sensation in the

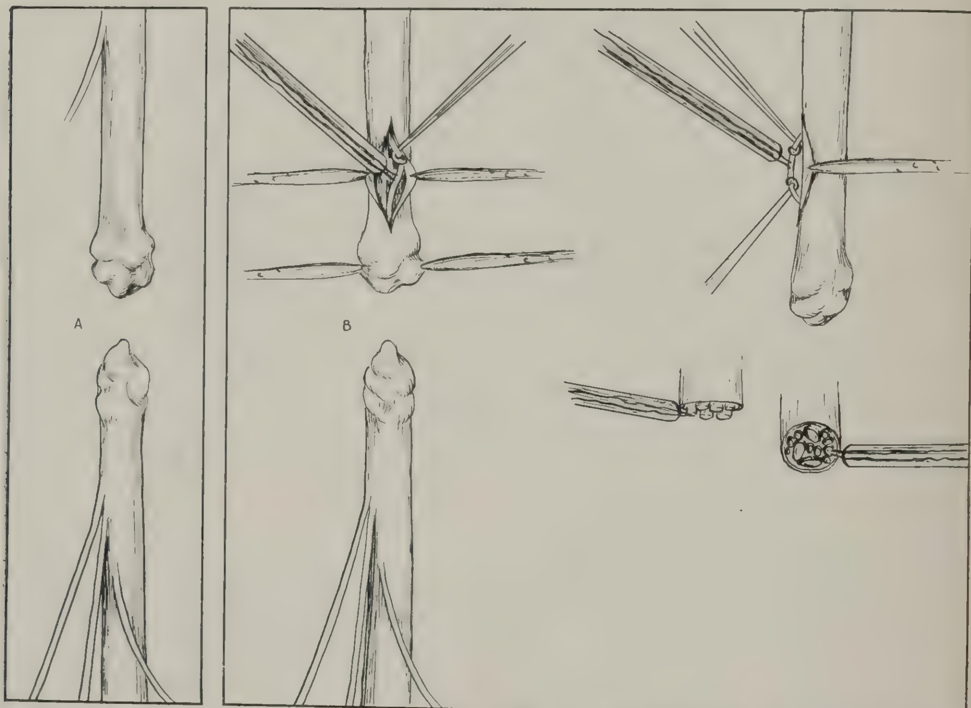

Fig. 152.—Electro-anatomic method of topographical identification. A, Motor branches in both proximal and distal segments serve to identify the motor sector of the nerve. B, Motor sector of distal segment is identified by the position of motor branches. The proximal segment, having no branches to permit anatomic identification of intraneural topography, the nerve sheath is opened and the nerve bundles identified by faradic irritation, which is most effective in determining sensory bundles; occasionally the stimulation of bundles at the end of a resected nerve may give some assistance in topographical identification, though it is of less value and the stimulation is difficult to control

normal cutaneous area supplied by that bundle. If the current be too strong, the patient will complain of pain. If a motor bundle be stimulated, the patient will experience a sensation of muscular effort due to stimulation of myosensory fibers. For example, in the musculospiral nerve, if a motor bundle be subjected to mild faradic irritation in the arm, and the patient experiences a sensation of "pulling up" of the wrist or straightening of the fingers, the surgeon will know that he is stimulating motor fibers to the carpal extensors or to the extensor communis digitorum, and he has thus localized the motor side of the nerve trunk above the lesion. If, however, the patient experiences a

tingling sensation which is localized on the dorsum of the thumb or hand, the surgeon is then stimulating the sensory area of the nerve trunk.

The electro-anatomic method of funicular identification consists, therefore, in locating the motor portion of the nerve trunk in the distal segment, by identifying the intraneural position of motor branches, while in the upper segment of the nerve trunk the sensory portion is localized by weak faradic stimulation; in approximation, the surgeon is thereby able to effect a certain degree of physiologic alignment. This method is of value principally in areas where the upper segment of the divided nerve is not giving off motor branches, such as the median nerve in the upper arm. After the identification of the physiologic constituents of the proximal segment, the nerve trunk may be anesthetized with novocaine, and the neuroma and scar tissue resected, preparatory for approximation. In the electrical identification of bundles, it is essential to begin with the weakest possible current, the needle points of the electrode being separated not more than 2 mm.

Electric funicular identification is an extremely delicate procedure, and it requires the greatest care and gentleness, particularly to insure a current sufficiently weak to avoid pain on stimulating sensory bundles; a current which can be felt on the tip of the tongue is often too strong for sensory bundle stimulation.

BUNDLE IDENTIFICATION

After resection of the scar tissue from the ends of the nerve, the individual nerve bundles stand out prominently, and some surgeons have attempted to effect funicular identification by bundle matching. In Ney's experience this has not proved feasible, because the bundles of the lower segment, which are but the empty channels from which the neuraxons have disappeared by degeneration, in no way correspond either in number or in size with the intact bundles of the proximal segment.

APPROXIMATION TECHNIQUE

After both segments of the divided nerve have been exposed and precautions taken to prevent torsion during approximation, and the surgeon has assured himself of the possibility of correcting the defect, the nerve ends may be prepared for suture. The resection of nerve ends, however, must not be done if there is any possibility of having to resort to the two-stage operation to correct a defect.

In preparing a nerve for suture, the neuroma of the proximal end is resected in serial sections about 1 mm. thick until normal-appearing nerve bundles present themselves throughout; this resection should be continued until the nerve bundles are free from scar tissue. The resection of the nerve end should be made with a very sharp instrument, and for this purpose a new safety razor blade held in strong forceps serves admirably. If it is desired to preserve the sectioned ends for further study, the order of their arrangement may be maintained by stringing them upon a piece of suture material, after which they may be placed in alcohol or formalin. The end of the distal segment does not present a typical neuroma as does the proximal end and is often

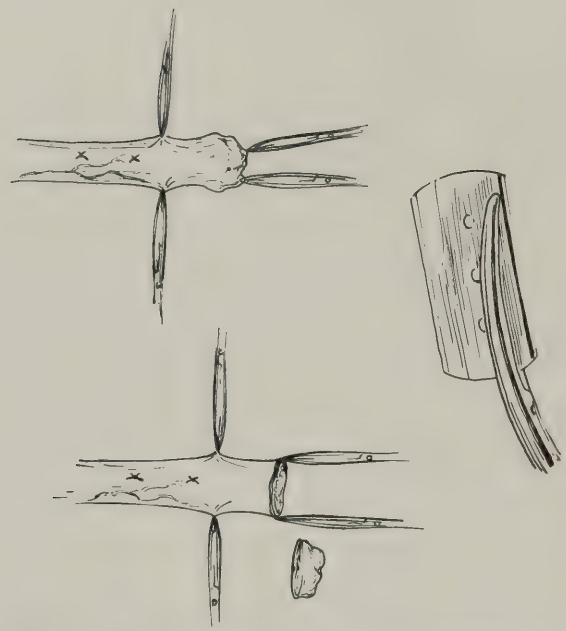

FIG. 153.—Application of forceps to an immobilized nerve during section. (Ney. *Annals of Surgery*, 1921)

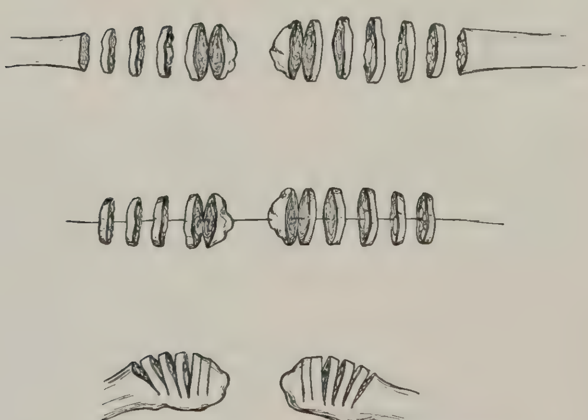

FIG. 154.—Sectioning of nerve ends for removal of neuroma and scar tissue. Method of preserving sections in order of removal. (Ney. *Annals of Surgery*, 1921)

found to taper off into the surrounding scar tissue, in which it is lost. It should be sectioned carefully beyond the point of scar invasion to a point where the bundles stand out freely, using the same technique as that used in sectioning the proximal end.

After the nerve ends have been prepared, the first fine silk suture is placed, passing just through the nerve sheath, not deep enough to encroach upon or to constrict the bundles. The first suture is of great importance, in that it

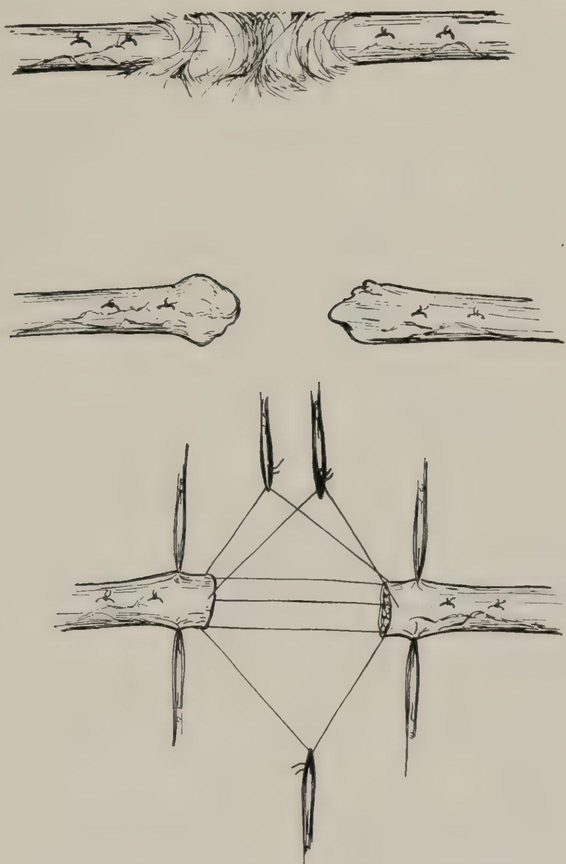

FIG. 155.—A, Technique of end-to-end suture, showing the placing of identification sutures before a nerve is removed from scar tissue. B, Exposed nerve before resection of neuroma and scar from its ends. C, Nerve resected, identification forceps applied, and three quadrant sutures placed. (Ney. *Annals of Surgery*, 1921)

should remain the guide to alignment in the placing of subsequent sutures, and in the placing of this suture the alignment of identification sutures should be assured. The second and third sutures are now placed in the center of the medial or lateral quadrant of the nerve trunk. The ends of these sutures are grasped by forceps and not tied until all quadrant and intermediate sutures are accurately placed. In placing the fourth or posterior quadrant suture, the nerve trunk is rotated by passing the forceps holding the lateral suture

under the nerve trunk, rotating it to the medial side, while the medial quadrant suture is pulled over to the lateral side. This rotates the nerve trunk so that its posterior quadrant is exposed, when its suture may be accurately placed. Between each quadrant suture one or more intermediate sutures may be required, depending upon the size of the nerve trunk. Adjacent quadrant sutures are held taut, during the placing of each intermediate suture, to assist in accurate spacing. A sufficient number of sutures should always be used to assure perfect approximation of the nerve sheath, thereby preventing the neuraxons from wandering outside the nerve trunk at the suture line, where they would be

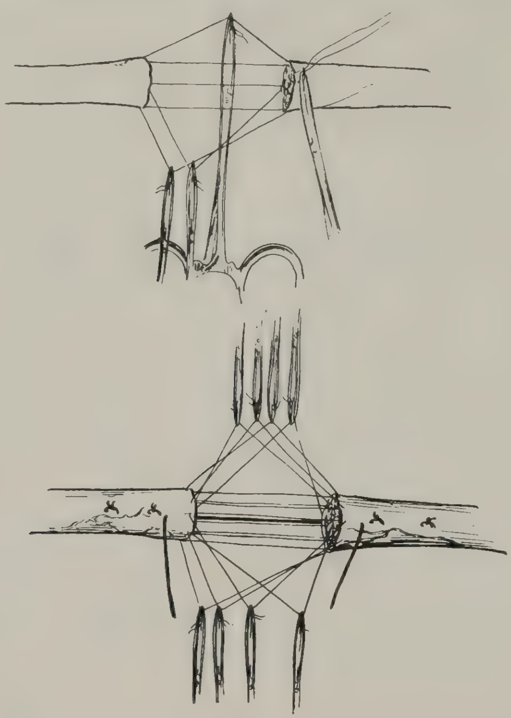

FIG. 156.—A, Rotation of the nerve for the purpose of placing the posterior quadrant suture. B, Intermediate sutures placed and all sheath sutures held in position to prevent rotation in placing a tension suture. (Ney. *Annals of Surgery*, 1921)

physiologically lost and tend to form a sensitive neuroma. After all sutures have been placed the nerve should be relaxed by flexing the governing joint and the nerve ends gradually approximated by taking in the slack of the sutures. If considerable tension upon the sutures is necessary to produce approximation, a *tension suture* of plain catgut may be passed completely through the nerve trunk 1 cm. beyond its ends to diminish the tension on sheath sutures. It is essential in placing the tension suture that the forceps holding the sheath sutures be equally arranged on each side, corresponding to the sheath sutures of that side, and these sutures held taut to prevent distortion of alignment during its insertion. Care must be exercised to prevent tearing of the sheath sutures

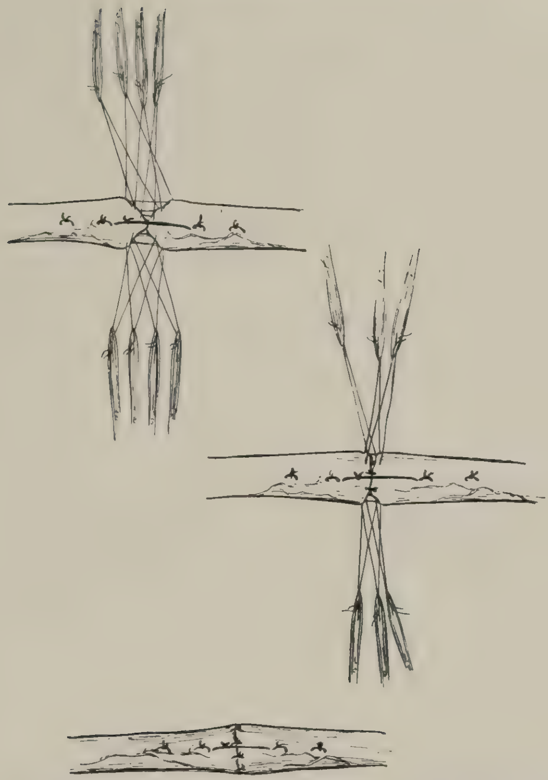

FIG. 157.—A, Approximation by tension suture. B, Order in which sheath sutures are tied after nerve is approximated by the tension suture. C, End-to-end suture completed. (Ney. *Annals of Surgery*, 1921)

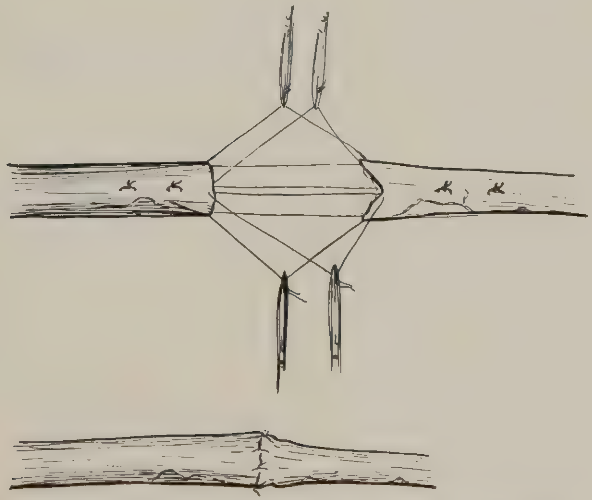

FIG. 158.—The V section of a small distal segment used for the same purpose as the diagonal section in Figure 159. (Ney. *Annals of Surgery*, 1921)

when force is required to draw the tension suture through the nerve trunk. With all sheath sutures held taut in their consecutive arrangement, the tension suture is tied as the nerve ends are approximated. The sheath sutures are individually picked up and tied, beginning with those placed proximal to the tension suture; as the sheath sutures are being tied, every second suture is left uncut to facilitate rotation of the nerve trunk for subsequent inspection of the suture line. If sheath approximation is found to be imperfect at any point additional sutures may be placed for its correction. Frequently, after sectioning the nerve ends, there is some bleeding, which may usually be controlled by

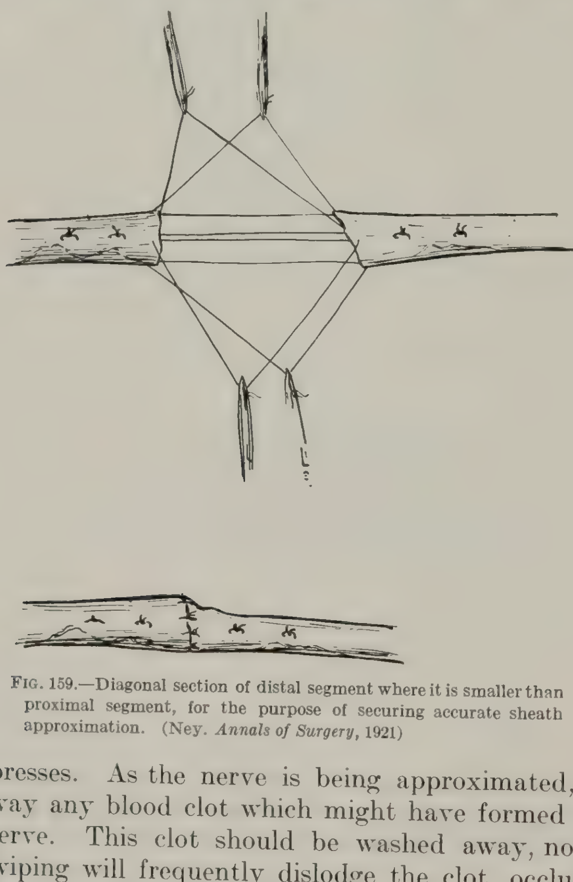

FIG. 159.—Diagonal section of distal segment where it is smaller than proximal segment, for the purpose of securing accurate sheath approximation. (Ney. *Annals of Surgery*, 1921)

wet cotton compresses. As the nerve is being approximated, care should be used to wash away any blood clot which might have formed over the end of the sectioned nerve. This clot should be washed away, not wiped, as the traumatism of wiping will frequently dislodge the clot, occluding the end of the vessel, and the bleeding will be renewed.

THE PREPARATION OF THE NERVE BED

When the original nerve bed contains an excess of scar tissue, a satisfactory new bed may be provided by placing a few deep sutures through the adjacent muscles, which may be drawn together under the nerve, thereby burying the old bed and providing one more favorable to the needs of regeneration. It must be remembered in the preparation of a nerve bed, however, that scar tissue may be limited only by the avoidance of tissue trauma and by

adequate hemostasis; therefore, in interposing adjacent muscular tissue for the formation of the new bed, it is desirable that untraumatized muscle be used when available. When scar tissue is excessive and normal muscular tissue is not available for the preparation of the nerve bed, the nerve may be brought to a superficial position. Occasionally in extensively scarred areas, neither muscle nor superficial fat will be found available for the protection of the nerve; it then becomes necessary to transpose the nerve by directing its course through adjacent intermuscular planes. When, however, the length of the nerve does not permit transposition, the surgeon must resort to plastic procedures in which normal skin and superficial fascia from adjacent regions are shifted to cover the scarred area. When adjacent fat is not available for plastic procedures of this type, skin and fat from the abdominal wall may be transplanted by the pedunculated flap method.

After a satisfactory bed has been provided, all blood clots should be gently washed away by a running stream of warm saline solution. The common habit of wiping incisions with gauze, instead of sponging, is to be discouraged as it causes unnecessary trauma to the wound and tends to increase oozing. It is usually advisable to drain all incisions, when there has been extensive dissection, by one or two well-placed pieces of rubber dam, which should be adequate to care for any subsequent oozing. This drainage should be removed at the end of 48 hours.

PARTIAL NERVE LESIONS

Occasionally a missile will sever only a part of a nerve trunk, causing a partial lesion; or a portion of the nerve may suffer accidental or intentional surgical injury during débridement, or in the removal of a nerve tumor. In several instances, the writer has found fragments of bone driven into the nerve trunk; in one case the musculospiral nerve had been penetrated by a hypodermic needle during typhoid inoculation, resulting in a permanent injury to the fibers supplying the extensor indicis. The majority of gunshot wounds involving the sciatic trunk are partial lesions, usually involving its external or peroneal portion.

The frequency with which partial lesions are met adds greatly to their importance and demands special consideration, for in the surgical treatment of such lesions it is essential that the operator, in his efforts at repair, does not inflict additional surgical trauma to such intact nerve fibers as might have escaped the original injury. A careful preoperative determination of individual muscle function is extremely important, inasmuch as it should indicate the exact extent of nerve injury and incidentally determine the functional importance of intact nerve fibers.

TECHNIQUE OF REPAIR IN PARTIAL LESIONS

If the nerve trunk, on exposure, exhibits a central or lateral neuroma, partial excision and approximation are required. If the preoperative examination indicates a high degree of functional integrity, the surgeon may rest assured that the "neuroma" is composed mostly of scar tissue, and its removal should

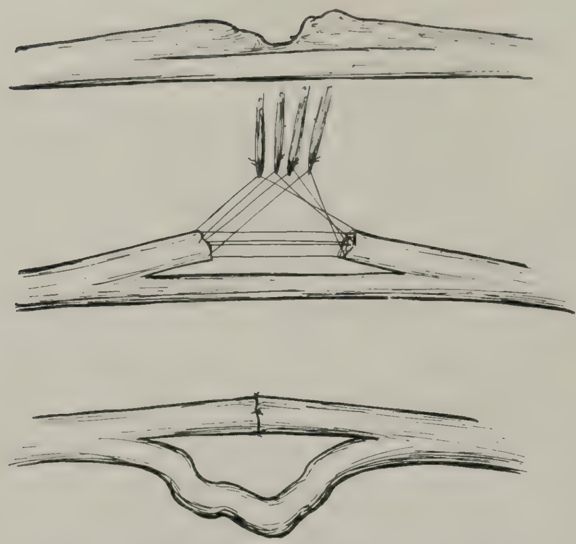

FIG. 160.—A, Partial lesion of a nerve trunk. B, Isolation of the interrupted portion from the physiologic normal portion. Quadrant sutures placed for approximation. C, Approximation in partial suture, such as a partial division of the sciatic nerve, showing relaxed undivided portion of the nerve. (Ney. *Annals of Surgery*, 1921)

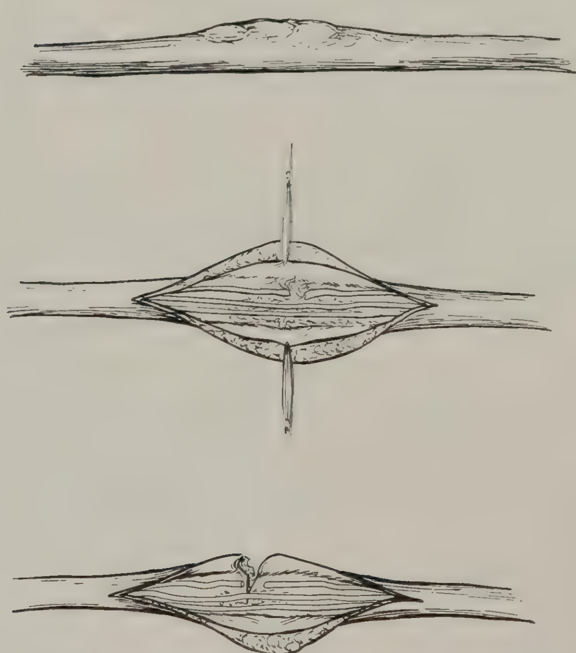

FIG. 161.—A, Partial lesion of a nerve trunk, where gross anatomic isolation of functionally intact portion of a nerve can not be made as in Figure 160. B, Opening of the nerve sheath, showing involvement of bundle. C, V-shaped incision of sheath by which approximation of the bundle is made possible. (Ney. *Annals of Surgery*, 1921

be attempted only after the nerve trunk has been longitudinally opened for some distance, and the normal bundles carefully separated from those incorporated in scar. Such bundles as appear to pass directly into the scar tissue should be carefully isolated above and below the lesion and subjected to weak faradic stimulation with a needle-point bipolar electrode. When faradic stimulation of a nerve bundle, distal to the lesion, is accompanied by muscular contraction (not due to diffusion of current), the surgeon may feel assured that the bundle is anatomically intact and should be dissected from the scar tissue with great care, avoiding traction, as nerve bundles are very easily torn. Bundles which give no response during electrical stimulation may not be anatomically divided, but only subjected to a degree of compression sufficient to destroy their conductivity; they should be carefully followed through the scar tissue, if possible, to determine their anatomic continuity. If a bundle shows scar tissue infiltration, the infiltrated area should be resected and the bundle ends approximated by a single suture of arterial silk passed directly through the bundle. When bundles are not readily approximated because of a defect, a V-shaped portion of the nerve sheath may be resected, corresponding in width to the length of the defect; linen sutures may be used to approximate this portion of the sheath, and with its approximation the ends of the individual bundles will be brought together, overcoming their defect; bundle sutures may then be tied, care being used to obtain accurate end-to-end approximation without strangulation. After approximation of individual bundles has been satisfactorily effected, the nerve sheath should be only partially closed; the unclosed portion may be covered with some surrounding untraumatized tissue such as intact muscle sheath, or if this is not available, by a pedunculated or free fat transplant, extreme care being given to hemostasis. In partial lesion of the sciatic trunk in which preoperative examination reveals a total loss of peroneal or tibial function, the nerve should be exposed sufficiently low to obtain the natural line of cleavage between its component parts, which upon their separation may be sutured in their entirety, as individual nerves. When a nerve trunk is found to present evidence of almost complete anatomic division, retaining only a small degree of functional integrity, one is justified in resecting the entire trunk and effecting a complete suture, but all partial lesions retaining important functional integrity should be subjected to individual bundle examination and repair.

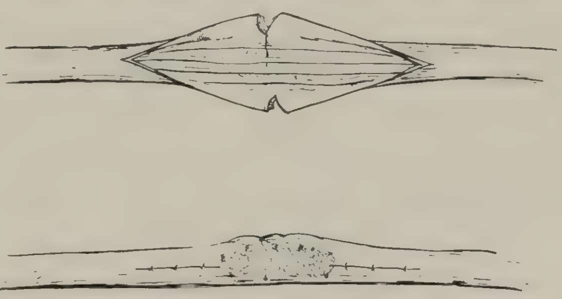

FIG. 162.—A, Approximation of the divided bundle accomplished by relieving tension in the approximation of the resected sheath. B, The thickened sheath is not entirely closed for fear of strangulation; the defect is covered by a fat transplant. (Ney. *Annals of Surgery*, 1921)

COMPRESSION AND STRANGULATION LESIONS

Nerve trunks, while retaining their anatomic continuity, may be compressed to such a degree as to interrupt their physiologic continuity. This com-

pression, if excessive, may result in complete strangulation with neuraxon degeneration. Strangulative lesions with degeneration do not present the typical neuroma, as is common to anatomic divisions, and the nerve can usually be traced through scar tissue as a more or less intact anatomic structure. Nerves may be compressed by extraneural scar tissue, bone callous, or even external pressure, such as ill-fitting splints, crutches, or the edge of operating tables. Surgical intervention is not indicated in the milder degrees of compression until sufficient time has elapsed for evidence of spontaneous regeneration. When, however, after three months there exists no sign of regeneration and the exact location of the lesion is known, the surgeon is justified in exploration. While extraneural lesions are probably the most common cause of nerve compression, two other types often exist which far more frequently demand surgical intervention: Compression or strangulation from nerve sheath involvement, and intraneural fibrosis.

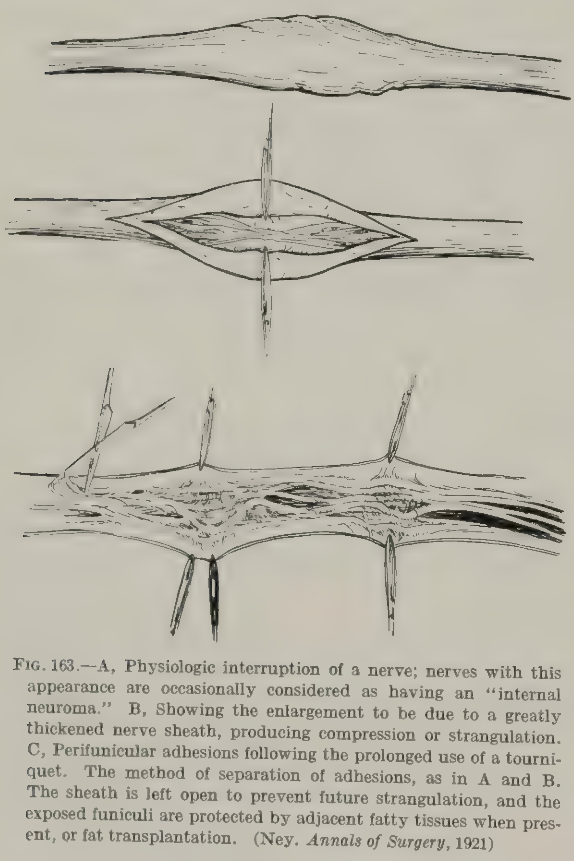

FIG. 163.—A, Physiologic interruption of a nerve; nerves with this appearance are occasionally considered as having an "internal neuroma." B, Showing the enlargement to be due to a greatly thickened nerve sheath, producing compression or strangulation. C, Perifunicular adhesions following the prolonged use of a tourniquet. The method of separation of adhesions, as in A and B. The sheath is left open to prevent future strangulation, and the exposed funiculi are protected by adjacent fatty tissues when present, or fat transplantation. (Ney. *Annals of Surgery*, 1921)

NEUROLYSIS

Many surgeons have been content with an external neurolysis when exposure revealed the nerve trunk to be anatomically intact; such a procedure has frequently given very disappointing end results, obviously, because of inadequate bundle decompression. When a compression lesion has been exposed and surrounding scar tissue removed (which constitutes an external neurolysis), the nerve trunk should be carefully palpated; if it be found soft, without evidence of a thickened sheath or intraneural fibrosis, the external neurolysis should be deemed sufficient.

When the nerve has an indurated appearance and presents undue hardness on palpation, decompression, or internal neurolysis is indicated. The nerve sheath is longitudinally incised, exposing the indurated portion, and gently held open with fine traction sutures or mosquito forceps. This intraneural exposure will usually reveal the nature of the compression, whether it be due to a thickened indurated nerve sheath or to an intraneural fibrosis. When the compression is confined to a thickened and indurated nerve sheath, the exposed bundles, though showing signs of compression, will be found intact, readily

isolated, and free from scar tissue. Such a condition is usually relieved by the simple decompressive procedure of opening the nerve sheath. When the sheath exhibits marked thickening the thickened portion may be resected, no attempt being made at closure. Occasionally the intraneural exposure reveals "matting" of the bundles by adhesions; intraneural neurolysis is then indicated. The bundles are gently dissected free from the scar tissue by inserting the blades of fine-pointed iris scissors which are spread, gently separating the bundles from the perifunicular adhesions. If, however, the bundles are found imbedded in a dense mass of scar in which they lose their anatomic identity, resection of this area is indicated, and the nerve united according to the usual technique for end-to-end suture.

THE ELECTRICAL EXAMINATION OF NERVES AT OPERATION

Important information may be obtained by the routine use of faradic stimulation of nerves when exposed at operation. The battery required is the ordinary type of single-cell faradic medical battery, in which the strength of current may be regulated by moving the core. A fine-pointed bipolar electrode is connected to the battery with plain copper or silver wires, which may be sterilized by boiling. Small glass beads may be threaded on each wire to prevent short circuiting. Ordinarily the bare ends of the wire may be used as a bipolar electrode, but for the more delicate procedure of funicular identification needle points should be used, these points having a separation at their end of approximately 2 mm. In beginning the test the weakest possible current should be used, the strength of which may be increased as desired, by the attendant manipulating the coil. The operator should assure himself that the connections are intact and the battery is working properly, by stimulating neighboring exposed muscular tissue whose nerve supply is normal.

When a compressed nerve is exposed at operation, it should be stimulated both above and below the lesion. If weak faradic stimulation above the lesion gives a response in the paralyzed muscles, it is doubtful whether the lesion exposed is responsible for any serious compression. Where such a condition is found to exist before the nerve has been decompressed, the diagnosis of an organic lesion is questionable, providing all the muscles respond to stimulation. It is possible, however, that the surgeon is dealing with a partial lesion and is stimulating intact fibers. A careful preoperative examination, however, should have demonstrated the probability of such a condition. Occasionally, an anatomically intact nerve may be exposed in a compression lesion, where stimulation above the lesion fails to elicit a response, while stimulation below the lesion gives definite muscular contractions; such findings are found only in the mildest grades of nerve compression, and a careful neurolysis will usually result in the passage of electrically excited impulses beyond the lesion, providing the nerve has not been traumatized nor stretched during the neurolysis. Trauma during neurolysis will frequently cause the disappearance of the electrical conductivity previously found.

ELECTRICAL IDENTIFICATION OF PHYSIOLOGIC COMPONENTS OF A DIVIDED NERVE

When a nerve is exposed under local infiltration anesthesia and before the nerve trunk has been anesthetized, it is possible by opening the nerve sheath of the upper segment to effect physiologic identification of the exposed bundles by weak faradic stimulation. The stimulation of a sensory bundle elicits a tingling sensation localized in the normal cutaneous sensory area of that nerve; if the stimulation is too intense, considerable pain may be experienced. Stimulation of a motor bundle is not associated with pain unless the current is diffused to sensory bundles. The stimulation of myo-sensory fibers, usually found in a motor bundle below a nerve plexus, gives a sensation of muscular action. (See technique of electro-anatomic funicular identification p. 963.) In partial lesions of nerves the physiologic intact portion of the nerve trunk may be determined by faradic stimulation.

The success of electrical identification of nerve bundles depends primarily upon an extremely careful and gentle technique. If the current used is a bit too strong, the patient is caused pain and the tests are difficult to control. The current also has a tendency to diffuse throughout the nerve trunk, stimulating all fibers and rendering the test valueless. When carefully and accurately applied it is an extremely valuable adjunct in identifying the physiologic components of a nerve trunk. In long-existing paralysis the stimulation of motor bundles will occasionally give no myo-sensory reaction; the same is true in the stimulation of motor bundles above a nerve plexus. The most reliable results obtained are from stimulating a completely formed branch, before it has left the parent trunk.

SECONDARY OPERATIONS FOR DEFECTIVE REGENERATION

Inasmuch as defective regeneration may take place in both nerve and muscle, it is essential in the absence of regeneration to decide definitely the nature of the regenerative defect.

MUSCLE REGENERATION

Primarily, degeneration in paralyzed muscles following peripheral nerve injuries is due to denervation; the longer a muscle remains denervated the more intense will the degenerative changes become. In muscles of small size these degenerative changes seem to become extreme, and after a period of 12 or 18 months the degeneration has progressed to a point where recovery is extremely doubtful. Small muscles, like the intrinsic muscles of the hand and foot, being innervated at a great distance, seldom recover after nerve injury if deprived of their nerve supply longer than one year. Therefore, secondary operations are, as a rule, not indicated for regenerative failure in muscles of small size with distal innervation. In muscles of larger bulk, whose nerve supply is usually derived at a higher level, the chances for regeneration are far more favorable; in regeneration of the injured nerve they receive nerve fibers much earlier than the smaller, more distally located muscles, and

their larger bulk insures their receiving a greater number of regenerated motor fibers. In the upper extremity regeneration occurs in about the same degree in muscles of comparative size, whether they be innervated by the musculospiral, median, or ulnar nerves, providing the lesion of these respective nerves occurs at about the same level and the period of their denervation is the same. In brachial plexus lesions, which are high lesions, the more distal muscles in the forearm, as a rule, show more extreme degeneration and less tendency to recover than those muscles deriving a higher innervation. In high sciatic trunk lesions recovery of the gastrocnemius is much more likely, because of its large bulk and comparatively high innervation, than is to be expected in the flexors or extensors of the toes. We may conclude, therefore, from a standpoint of muscle regeneration, that the longer a muscle remains paralyzed the greater will be its degeneration and the less likely will be motor recovery.

Reoperation on nerve trunks is indicated solely because of absent or defective neuraxon regeneration, and not because of defective muscle regeneration. While re-innervation is absolutely essential to muscle regeneration, it must be remembered that muscular tissue having undergone extreme degrees of atrophy will not regenerate to a degree of functional usefulness when re-innervated. It must also be remembered that defective regeneration frequently occurs in muscles which have undergone prolonged overstretching; also that muscles showing signs of regenerative changes may be late in responding to voluntary motor impulses, due to concomitant functional conditions and lack of reeducation. A muscle showing signs of increasing electrical and mechanical irritability is undoubtedly regenerating; a muscle completely devoid of electrical and mechanical irritability either has undergone complete degeneration, resulting in a fibrous transformation, or else it remains denervated.

NEURAXON REGENERATION

Neuraxon regeneration in its early stages may be determined only by Tinel's sign of formication. Regeneration, following suture of a peripheral nerve, occurs after the first month at the rate of about 3 cm. per month, providing regeneration is unimpeded. After the third month, formication should be elicited in the lower segment of the nerve; at the end of six months, it should be elicited 5 or 6 inches below the suture line with about the same intensity as the reaction obtained at the suture line. While this reaction gives evidence only of sensory fiber regeneration, it is probable that motor fibers contained in the same sheath have regenerated to the same degree. Tinel's sign is the only means we have at our disposal at the present time for determining neuraxon regeneration, until the regenerating motor and sensory fibers have reached their respective terminations and manifested their presence by a return of sensation and muscle regeneration. The absence of Tinel's sign in the distal segment of a sutured mixed peripheral nerve, after four to six months, definitely indicates an absence of neuraxon regeneration, providing this sign may be elicited with intensity at the suture line. When Tinel's reaction in the lower segment of the nerve is of considerably less intensity than at the suture line, defective regeneration may be definitely concluded. The state of a negative,

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or seriously defective neuraxon regeneration calls definitely for surgical intervention.

In certain instances, neuraxon regeneration may progress favorably down the distal segment of the repaired nerve without restoration of motor or sensory function, due to torsion of the nerve trunk during suture, with misdirection of fibers, resulting in their complete physiologic loss. This accident may occur to any degree, and doubtless many defective regenerative results are due primarily to this cause. We may, in general, classify regenerative failure into three groups: (1) Absent or defective neuraxon regeneration; (2) defective regeneration, due to disturbance of nerve pattern during primary suture; (3) persistence of muscle degeneration after reinnervation.

1. The factors responsible for absent or defective neuraxon regeneration will usually be found at the suture line. They are:

a. Defective approximation, in which the proximal segment of the nerve presents a secondary neuroma which calls for resection and accurate approximation.

b. Construction in the region of the primary suture by a scar infiltrated nerve sheath not sufficiently resected at the primary operation, which calls for decompression. The surgeon should assure himself that the exposed intraneural contents are not subject to extensive scar invasion; if such be the case, complete resection and a new approximation will be indicated. If the intraneural contents are found to be soft to palpation without evidence of scar infiltration, the defect should be considered as having been corrected by the decompression.

c. Construction by perineural scar tissue is usually the result of excessive tissue trauma, defective hemostasis, or infection following suture. Occasionally the failure to provide a suitable bed for the repaired nerve may be responsible; this obstruction to regeneration sometimes follows the use of foreign tissue, which at one time was used extensively to protect the suture line. Undoubtedly, experience has shown that the best protection a nerve may have is its own sheath; that an excess of scar tissue subsequent to operation can usually be avoided by paying due respect to the above enumerated causes. After the nerve trunk has been freed from constrictive extraneural scar tissue and found to be free from intraneural scar invasion, it should be transposed to a new and more favorable bed.

2. Defective regeneration, due to torsion of the nerve trunk during the original suture, calls for resection of the original suture line and reapproximation; in this, the surgeon must resort to topographical identification, which is considered in detail under the surgery of individual nerves.

3. Failure of muscle regeneration does not call for surgical intervention, in so far as the nerve is concerned. When the degenerated condition of the muscles has persisted for two or three years following a nerve suture with successful neuraxon regeneration, they should be considered as irretrievably lost and recourse should be taken to such supplementary procedures as will assist in correcting the defect. (See irreparable lesions of special nerves, p. 959.)

TENDON TRANSPLANTATION

Tendon transplantation, in peripheral nerve lesions, is indicated for the correction of defective motor regeneration, whatever may be its cause. It should not be resorted to, particularly when it entails a sacrifice of muscles and tendons, as most transplants do, until the persistence of the motor defect is definitely established or the extent of the nerve injury precludes the possibility of repair. Two exceptions to this rule at the present time are pronator teres transplantation for extension of the wrist, and the author's transplant for restoring opponens function to the thumb; both of these procedures may be executed without jeopardizing subsequent muscle regeneration or interfering with muscle action after regeneration. In fact, both procedures, particularly the latter, tend to relax the paralyzed muscles, making conditions more favorable for their regeneration. In irretrievable lesions of a peripheral nature, tendon transplantation offers a very valuable means of restoring, to some extent at least, movements lost by the original paralysis.

The general principles governing tendon transplantation are primarily the same in both upper and lower extremities, though the chief desideratum in the upper extremity is mobility, while in the lower extremity stability for weight bearing is more essential. To hope for successful functional end results following tendon transplantation, the surgeon must adhere strictly to certain general principles which experience has proved to be indispensable; the neglect of these primary requisites is but to invite failure, following which the after results may be more unsatisfactory than the former.

An important essential to the success of tendon transplantation lies in the mobility of those joints upon which the transplanted tendons act. A joint whose function is fixed in deformity will never respond to the action of transplanted tendons. Before tendon transplantation of any type is attempted, the surgeon should assure himself that the range of motion in these joints which are to be influenced by the transplantation must be fully adequate to functional needs and without restriction. An operation for tendon transplantation, therefore, must be definitely postponed until restricted joints are fully mobilized and tendon and fascial contractures completely corrected.

For restoration of function through tendon transplantation, only muscles with sufficient power and contractile vigor should be used. It is therefore essential that the surgeon be familiar with the ways and means of determining individual muscle function, and in the selection of a muscle for transplantation, its ability to do the proposed work should be definitely determined. A normally weak muscle should never be expected to assume a function requiring greater power than it ordinarily possesses. Though a muscle may hypertrophy, to a certain extent, to assume an additional burden, its power to do so is markedly limited and should not be too greatly relied upon.

While various rules have been promulgated from time to time, on the grounds of synergetic action, for the selection of muscles to be used in tendon transplantation, practical experience has demonstrated that certain deviations from these rules have been attended with considerable success. It is important, however, in selecting a muscle for the performance of a specific function that

it be adapted physiologically to that function. Although it is generally held that an antagonist should never be selected for tendon transplantation, it should be remembered that anatomic antagonists may not, in a strict sense, be physiologic antagonists. In the synergetic action of muscles, for the accomplishment of smoothly adjusted movements, a contraction in a certain group of muscles will call into play a relaxation of a physiologic antagonistic group. In the execution of certain other movements, however, a muscle anatomically antagonistic may contract simultaneously with its opponent, to fix a joint in a position which will supplement the action of the other muscles.

The determination of synergetic action in various movements is extremely complicated and can be comprehended only after a careful study of individual and combined muscle action. The surgeon is materially assisted, however, in the determination of those muscles of separate innervation, which contract simultaneously for the execution of a given movement, by the study of "trick or substitution" movements commonly seen in peripheral nerve injuries.

The maintenance of direct muscle pull from origin to insertion should be assured in tendon transplantation by long incisions and adequate tendon and muscle mobilization. A muscle with an obliquity of pull is much less effective than one pulling in a direct line. In the transplantation of tendons, therefore, free tendon mobilization and the avoidance of angulation are primary requisites.

The tunnel best adapted to transplanting is one directed beneath the fat of the superficial fascia, where adhesions are less apt to be dense. It is advisable, in planting the original incision, to avoid if possible the superimposing of skin and tendon sutures.

The amount of tension exerted upon a transposed tendon is frequently responsible for success or failure. A muscle is an elastic structure and its inherent elasticity and tone will cause shortening when its tendon is divided. In making an anastomosis, it should be held sufficiently taut to restore its normal tension, but must in no wise undergo a degree of stretching sufficient to produce a paresis. The joint to be acted upon must be flexed or extended to the degree to which the transplanted tendon is expected to act. If it is desired to procure complete extension of hand and fingers, they must be so maintained, in extension, during approximation of the tendon, and the anastomosis effected under sufficient tension, that when the anastomosis is completed and the muscle completely relaxed, it still is under a degree of tension comparable to that existing in the muscle previous to its transplantation.

After suture, the member must be maintained continuously in the position under which it was placed during transplatation, lest the sutures in the anastomosed tendon be avulsed or broken. This requires considerable care and attention on the part of the assistant during closure of the integument and the application of dressings. It is usually advisable to prepare a suitably moulded splint in advance, in order that it may be slipped into position without delay and without jeopardizing the anastomosis. In the preoperative preparation of the splint, it should be moulded to maintain exactly that position which the tendon transplant is expected to effect during its maximum action; however, the joints involved should not be sufficiently extended

or flexed to produce discomfort. The splint should be so arranged that removal of dressings is possible without disturbing the position of the extremity.

After the second week, passive movements may be instituted to prevent joint restriction, and to stretch the adhesions about the anastomosis before fixation occurs. These active and passive movements must be executed with extreme care, and controlled by one who is familiar with the nature of the operation and experienced in the treatment of these conditions. If healing of the skin is complete, gentle massage of the extremity may now be practiced.

After a period of one month the splint may be entirely removed during treatment, after which it is replaced. Two weeks later, the splint may be removed for a short time each day, which period may be lengthened as the transplanted muscles develop in strength. If after discarding the splint the muscles seem to become weaker, it should again be applied and worn continuously for a few weeks. A night splint is important and should be worn for a period of at least two months following the discarding of the day splint.

Reeducation consists in explaining to the patient the nature of the operation, demonstrating the original action of each muscle, and then the acquired action through tendon transplantation. It has been the writer's practice to have the patient instructed before the operation in the individual use of those muscles which will be used in transplantation. Frequently the use of electricity will demonstrate to a patient more clearly than any other means the action of his transplanted muscle. The progress in reeducation depends less upon the individual than upon the nature of his instruction. It is expedient that the surgeon keep these patients under his personal supervision until such a time as the ability is acquired to use his transplanted tendon properly.

Three months is usually required for the scar tissue, uniting the tendons, to become sufficiently hard to resist the strain of ordinary functional demand, and until this period has elapsed care should be used in preventing any undue strain falling upon the transplanted tendons.

INFECTED WOUNDS AND NERVE SURGERY

It is folly to attempt nerve repair in the presence of an infection or an open wound, and if during the course of a dissection pus is uncovered in bone or soft tissue, the attention should be directed to the removal of the infected area, and the nerve repair postponed until the infection is completely controlled and the wound entirely healed.

RECRUDESCENCE OF INFECTION IN CICATRIZED WOUNDS

Frequently our attention has been attracted to the recrudescence of an infection in wounds which have for many months been completely cicatrized. Wounds which have undergone a long period of suppuration may harbor latent infection for months or even years following their cicatrization, and during this period any form of tissue trauma, surgical or otherwise, may serve to initiate a recrudescence of the latent infection, which may be attended with high temperature, great pain, and all the symptoms of a local or even a general sepsis. It is essential, therefore, that a sufficient period of time be allowed to elapse following the healing of an infected wound to insure to some degree the

safety of a surgical invasion. When suppuration has attended the healing of a wound involving only soft parts, an aseptic surgical operation in the vicinity of this wound should not be attempted until cicatrization has been complete for a period of at least three months. When the suppurative process has involved osseous structures, the period of waiting should be prolonged to at least six months, and in many instances the operation will not be safe for a period of one year, particularly if there is a history of repeated breaking down of the wound. Inasmuch as this attitude of conservatism or watchful waiting may jeopardize the ultimate outcome of nerve repair, because of delayed intervention, a more active policy may be pursued for the clearing up of scars suspected of harboring infection.

We have satisfactorily used the following method of testing for latent infection: For two days previous to the test the patient is confined to bed and his temperature recorded every four hours, a leucocytic count having been made on two alternate days. The scar is then subjected to vigorous massage for a period of five minutes. Following this, for one week the four-hour temperature is recorded and daily leucocytic counts continued. Careful daily inspection of the wound is made for local signs of inflammation, such as swelling, redness, or increased local temperature. A wound harboring infection will usually reveal its presence by both a local and a general reaction. An elevation of temperature, an increased leucocytosis, or signs of a local inflammatory nature will usually be observed if there be a dormant infection. If no reaction be elicited, it may be considered safe to attempt a clean operation; if, however, a reaction does occur following the massive massage, excision of the scar tissue followed by wound sterilization and closure should be attempted, and the nerve operation delayed until this wound has been completely healed for a period of three months.

PRIMARY OPERATIONS

There can be no doubt regarding the advantage of immediate nerve suture following wounds in which, during examination, the nerve is found to be completely divided. Inasmuch as most lacerated wounds are infected, the question naturally resolves itself into a discussion of the advantages and disadvantages of suturing a nerve in the presence of infection, or where infection seems inevitable. Before the days of wound excision and successful sterilization, one could not suture a nerve and hope for satisfactory regeneration to any degree.

If wound excision and sterilization seem probable, the surgeon is justified in approximating the ends of the nerve with fine sutures, or even by a single tension suture, with the primary object of preventing retraction and fixation of the nerve ends, thereby diminishing the extent of the continuity defect during the process of healing and perhaps making less difficult a secondary operation. In any wound potentially infected, the excision of nerve ends and the extensive exposure necessary to satisfactory approximation should be vigorously discouraged, as this procedure invariably opens up new channels for infection, is rarely successful, and greatly complicates the almost inevitable secondary suture. It is therefore advisable in all open wounds, complicated by nerve injury, to first control infections, delaying the operation for nerve repair until such a time as it may be aseptically accomplished.

NERVE INJURY DURING DÉBRIDEMENT

The efficacy ot wound débridement has become established. In the hands of the skilled and experienced surgeon, débridement with primary suture has in many instances resulted in primary healing, but in the hands of a novice it is a procedure nothing less than hazardous. There can be little doubt that many nerves receive their first injury from the scalpel of the surgeon during débridement. The writer, on one occasion, witnessed the excision of 2 inches of the musculospiral nerve, during a spectacular débridement of a gunshot wound.

Every injured extremity, having undergone débridement or any other operative procedure subsequently revealing a nerve injury, casts serious reflection on the operating surgeon, if the preoperative record fails to record the presence of that nerve lesion. The ease and rapidity with which an injured extremity may be examined for the presence of a complicating nerve injury leaves no excuse for its oversight in the preoperative records; a later discovery certainly throws the burden of responsibility upon the operator.

AMPUTATION NEUROMAS

The development of a neuroma at the end of a nerve, particularly when the neuroma is incorporated within the scar of an amputation stump, may cause extreme discomfort or pain, which is intensified by the pressure of amputation prosthetic appliances. To prevent subsequent annoyance of a painful amputation neuroma, the nerve, at the time of amputation, should be withdrawn and resected at as high a level as possible and injected with 80 per cent or absolute alcohol. If a nerve is not injected with alcohol, a neuroma will invariably form, but if the neuroma is located some distance above the cicatricial tissue of the stump, it is seldom subjected to irritation.

TREATMENT

A neuroma incorporated in the scar tissue of a stump usually calls for removal, with high section of the nerve. Frequently it is not considered advisable nor desirable to increase the scar of the stump by an additional incision; in such instances the nerve involved may be exposed some distance above the neuroma, injected with alcohol and sectioned. This procedure is quite as satisfactory as the removal of the neuroma, as it permits degeneration of its contained nerve fibers. Occasionally, the surgeon may resort to a plastic procedure on the larger nerves to prevent the formation of a subsequent neuroma. (See fig. 164.)

It is essential in each instance to determine the nerve responsible for the irritation. Pressure or percussion in the painful region will usually elicit tingling, which is localized in the cutaneous area normally supplied by that nerve. For example, if after an amputation of the arm a painful neuroma develops in the stump, and percussion of that neuroma elicits tingling localized in the little finger, the surgeon will know that the neuroma is of the ulnar nerve; if it is located in the second or third fingers, the median nerve will require resection. It is important to accurately determine the nerve responsible for

the pain. The writer has on several occasions seen a persistence of pain after neuroma removal, obviously because there were several neuromas in the stump and the neuroma responsible for the painful syndrome was unfortunately missed, a proper localization evidently not having been made.

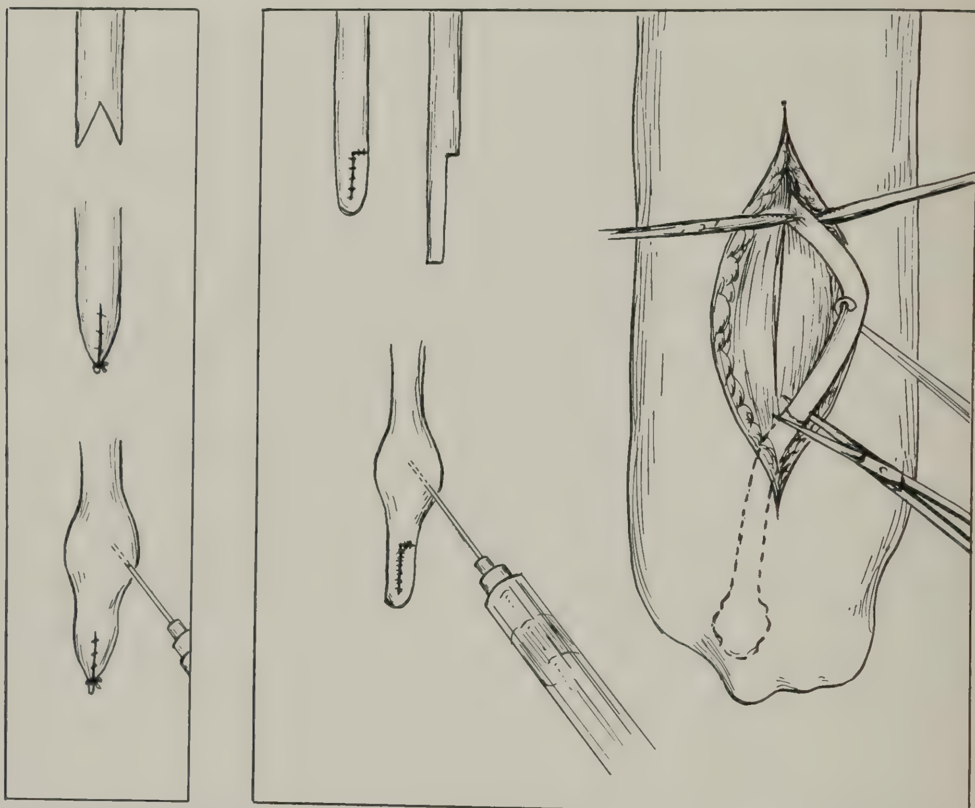

FIG. 164.—Plastic procedures and alcoholic injection to prevent the formation of amputation neuromas

THE BRACHIAL PLEXUS

GENERAL ANATOMY

The brachial plexus is formed by the anterior primary divisions of the fifth, sixth, seventh, and eighth cervical and first thoracic nerves, located in the posterior triangle of the neck and in the axilla. While the brachial plexus varies often in its formation, in that the fourth cervical nerve and the first thoracic may give a greater or lesser number of fibers to its formation, its general anatomy is fairly constant. Minor variations in the origin of branches will occasionally be found, but these anomalies are not sufficiently great to modify the surgical principles involved in attempting physiologic reconstruction of the plexus.

The plexus first consists of three primary trunks, lying upon the scalenus medius muscle; the upper trunk is formed by the fifth and sixth cervical nerves, the middle trunk by the seventh cervical, and the lower trunk by a

union of the eighth cervical and first thoracic nerves. Each of these primary trunks subsequently divide into an anterior and posterior division, which ultimately form the three plexus cords. The anterior divisions of the upper and middle trunk form the outer cord, which terminates by dividing into two branches, the musculocutaneous and the outer head of the median. The anterior division of the lower trunk forms the inner cord, which ultimately breaks up to form the inner head of the median, the ulnar, and the greater and lesser internal cutaneous nerves. The posterior divisions of the three primary trunks unite to form the posterior cord of the plexus, which terminates by dividing into the circumflex and musculospiral nerves. In the region of the clavicle, the three primary trunks divide into their anterior and posterior divisions, which are often comparatively short and lie lateral to the subclavian artery in close relation to the apex of the lung. Just below the clavicle, the anterior and posterior divisions of the primary trunks arrange themselves into the three plexus cords, which surround the axillary artery in its second portion, the outer cord lying upon the outer side of that vessel; the inner cord on its inner side; and the posterior cord behind. In the region of the coracoid process of the scapula, these cords divide into their terminal branches to supply the musculature of the arm and provide sensation to its integument.

A number of branches are given off from the brachial plexus to muscles of the shoulder girdle; the course of most of these is relatively short and they do not often lend themselves readily to surgical repair. Attention, however, must be directed to some of the larger and more important branches, which must be recognized and preserved in the surgical reconstruction of the plexus.

The *long or posterior thoracic* nerve usually arises by three roots from the fifth, sixth, and seventh cervical nerves, close to the intervertebral foramina. This nerve is very long and passes down behind the brachial plexus and axillary vessels along the outer surface of the serratus magnus muscle, which it supplies.

The *suprascapular* nerve arises from the lateral border of the upper trunk and passing obliquely outward beneath the trapezius and omohyoid, supplies the supraspinatus and infraspinatus muscles. In the dissection of the upper trunk, the suprascapular nerve should be identified and carefully preserved, or individually sutured if necessary, to preserve or restore function in the spinatus muscles; this is particularly important in deltoid paralysis.

The *subscapular* nerves, usually three in number, arise from the posterior cord below the clavicle and supply the subscapularis, teres major, and latissimus dorsi muscles. The importance of preserving these branches is obvious in the presence of a deltoid paralysis.

The *anterior thoracic* nerves are two in number and supply the pectoral muscles. The external and larger of the two arises from the outer cord of the plexus and passing inward crosses the axillary artery and vein, where it is distributed to the under surface of the pectoralis major. The inner anterior thoracic nerve arises from the inner cord and passing behind the axillary artery, it curves forward between the axillary artery and vein to the under surface of the pectoralis minor. Anterior to the axillary artery, the external and internal thoracic nerves are commonly united by a filament from the external nerve.

It should be remembered, therefore, in the dissection of the brachial plexus that in exposure of the upper trunk, the suprascapular nerve must be identified and preserved. In dissection of the posterior cord, the subscapular nerves require the same consideration, and in the dissection of the outer and inner cords, the external and internal anterior thoracics should be identified and preserved to retain pectoral function. The thoracic nerves are particularly liable to injury during dissection and isolation of the axillary vessels; their early identification during this procedure is important.

SURGERY

Traumatic lesions of the brachial plexus are fairly common in both civil and military life. The nature of these injuries may be direct, in which portions of the plexus are involved by penetrating wounds; or indirect, which are due more frequently to stretching of the plexus, the mechanism of which consists in forcibly depressing the shoulder while the neck and head are forced to the opposite side, greatly increasing the shoulder and neck angle. Indirect injury may result in lesions of varying degree, and in severe cases roots may be completely avulsed from the spinal cord. The avulsion more commonly takes place just external to the intervertebral foramina and often is confined to the upper roots of the plexus. Not infrequently, such injuries are limited to an overstretching of the upper trunk, which may or may not cause rupture of its intraneural constituents, the entire nerve sheath usually remaining intact. In such lesions spontaneous regeneration will probably occur under appropriate splinting and relaxation treatment. There are, however, certain anatomic factors in this region which tend to inhibit spontaneous regeneration. The brachial plexus is closely covered by the prevertebral layer of the deep cervical fascia, and indirect lesions of the plexus, with or without rupture, are often attended with hemorrhage under the fascia layer, which may be responsible for primary compression and ultimate more or less dense scar formation. These adhesions between the plexus and the prevertebral fascia are the most conspicuous features of the lesion, which upon exposure presents itself as a mass of scar tissue. It is usually only after careful sharp dissection of this fascia from the plexus that it is possible to proceed with identification of the individual anatomic plexus constituents, and not infrequently a thorough neurolysis of the plexus will be all that is required. While lesions of the upper trunk and outer cord are more common following indirect injury from stretching, lesions of the lower portion of the plexus more often result from direct trauma. The proximity of the lower plexus to the apex of the lung and important vascular channels makes penetrating wounds in this region particularly serious, frequently leading to an early fatal termination from hemorrhage. The relation of the trunk of the brachial plexus to the axillary artery is responsible for many combined lesions in which hematoma and subsequent scar tissue simultaneously compress the nerve trunks and vascular structures, combining ischemia with compression paralysis and often resulting in painful paralytic syndromes. Aneurysm is not an uncommon complication in lower plexus penetrating wounds. The relationship of the lower trunk of the plexus

to the first rib and the pleura are likewise anatomic conditions peculiar to the plexus, often greatly complicating the nerve lesion.

Exact anatomic knowledge and adequate exposure are essential in nerve surgery, regardless of the location; in the surgery of the brachial plexus these primary requisites are indispensable. At best, the end results of severe brachial plexus lesions are disappointing. Manifestly, many of these severe lesions are practically hopeless from a surgical standpoint, due to the fact that the lesion lies within or closely approximating the intervertebral foramina. It is well that the surgeon appreciate the technical difficulties which at present limit anatomic reconstruction in lesions involving the roots within or proximal to the intervertebral foramina. Plexus injuries associated with avulsion of the roots within the spinal canal are usually associated with some cord involvement, which will be evident on a systematic neurologic examination. Lesions within the intervertebral foramina will usually involve both anterior and posterior divisions of the cervical nerves, which will be evidenced by the addition of a dorsal anesthesia in the cervical region corresponding to the dorsal rami of the cervical nerves. The motor branches contained in the dorsal rami are distributed in a manner which does not readily lend itself to this differentiation; however, the sensory impairment referred to should place the involvement within the intervertebral foramina. The presence of a paralysis of the serratus magnus innervated through the long thoracic nerve whose branches are given off from the anterior divisions of the fifth, sixth, and seventh cervical nerves close to the intervertebral foramina will indicate a lesion in this location, particularly if the rhomboids are found to be involved. Therefore (1) brachial plexus lesions associated with spinal cord involvement usually preclude the possibility of repair; (2) lesions associated with a dorsal area of anesthesia corresponding to the dorsal cervical divisions likewise preclude the possibility of repair, due to involvement within the intervertebral foramina; (3) lesions associated with paralysis of the serratus magnus and rhomboids make extremely doubtful the possibility of repair, due to the proximity of the injury to the intervertebral foramina; (4) plexus lesions associated with sympathetic involvement (Horner's syndrome—myosis, enophthalmus, and narrowed palpebral fissure) indicate a lesion involving the eighth cervical nerve within or immediately adjacent to the intervertebral foramen, which greatly diminishes the possibility of repair in this region.

While the presence of the above types of brachial plexus lesions usually precludes the possibility of repair, the surgeon may feel the desirability of giving the patient the benefit of any doubt; the justification of assuming the risk of a long, tedious exposure is found in the fact that in the hands of an experienced neurologic surgeon there is little chance of increasing the disability and there may be a possibility of reconstructing some portion of the plexus. However, upon exposure, if the surgeon is content with simply approximating nerves, without regard to original physiologic pattern, even though the operation be followed by a regeneration of nerve fibers, the physiologic outcome will be such a distortion of motor and sensory function, as to exclude any possibility of usefulness in the extremity. The writer has seen several instances of brachial plexus lesions, following suture, in which neuraxon regeneration was active,

but with distortion of nerve pattern, resulting in most perplexing combinations of motor response and sensory localization. At least in the repair of the brachial plexus, the surgeon should by all means endeavor to approximate corresponding roots, trunks, and terminal branches, though even when this is accomplished and regeneration of nerve fibers is successful, it will be found that if there has been a torsion of the nerve trunk during suture, the ultimate physiologic outcome in that particular trunk will be more or less defective.

These facts will serve to partially explain the many instances in which sutures of the brachial plexus have been attended with such poor functional results. In order to avoid these unsatisfactory terminal results, the surgeon should fortify himself with such degree of anatomic and physiologic familiarity with the brachial plexus as will permit him, during repair, to conserve, as much as possible, its original pattern. If the surgeon feels that he is not sufficiently familiar with the intrinsic plexus anatomy to practice physiologic reconstruction, he had better confine his efforts strictly to a careful and painstaking neurolysis—which conservative attitude, in all probability, in the great majority of cases, will be attended with a more satisfactory functional end result. When, however, there has been an actual division of a portion of the plexus, its repair should be conducted with all precautions toward the prevention of distortion of the nerve pattern, by eliminating torsion during suture.

Most direct lesions involving the brachial plexus above the clavicle result in injury to the primary trunks, or their anterior or posterior divisions, while lesions below the clavicle usually involve the cords or their terminal branches. Penetrating wounds seldom involve the entire plexus, and it is usually possible, by careful preoperative examination of individual muscle function, to determine the exact location of the lesion. The surgeon so armed with a precise knowledge of plexus anatomy and clinical localization, will be able, after identification of the various intact branches by faradic stimulation, to definitely locate the lesion. This having been accomplished, should complete division be found, he will be able to effect reconstructive suture by uniting respective trunks without torsion with the aid of identification sutures and branch identification. For example, if the lesion compromises the terminal portion of the inner cord, involving the inner head of the median, ulnar, and internal cutaneous, the relative position in reconstructive suture would be: The inner cord of the median to the upper or lateral part of the anterior division of the lower trunk; the internal cutaneous would occupy the lower and medial side of the trunk; the ulnar, the center of the trunk between the inner head of the median and the internal cutaneous. To prevent torsion of the proximal segment, the position of the eighth cervical nerve would indicate the upper or lateral portion of the root; the position of the first thoracic, the lower portion of the root; and the posterior division, its posterior surface.

This type of anatomic reconstruction during suture, while by no means perfect, in that shunting of fibers is still possible in the terminal segments, will promise the highest degree of efficiency compatible with our present knowledge of ways and means to preserve intraneural topography. While this is purely an anatomic method, a careful study of the nerve trunk, its formation, the

position of terminal branches, etc., will usually serve to prevent serious torsion. The writer finds that the use of an enlarged anatomic chart in a convenient position in the operating room is of great service in assisting the visualization of reconstructive requirements in the surgery of brachial plexus lesions. The chart should indicate the respective muscles innervated by each primary, secondary, and terminal division of the plexus, so that in electrical stimulation, precision in identification may be facilitated. It is needless to state at this point that in preparing the field for operation the entire arm should be included, in order that it may be properly exposed and manipulated for inspection of muscle action during electrical stimulation of nerve trunks and branches.

TECHNIQUE OF EXPOSURE

The patient is placed upon his back with head abducted and rotated to opposite side, and shoulder depressed; a sand bag placed between the shoulders is often of value in maintaining this position. A "step-shaped" incision has been found the most desirable for complete exposure of the plexus. The upper longitudinal limb of the incision parallels the posterior border of the sterno-mastoid muscle to a point just below the clavicle; turning outward, the incision transverses the thorax along the lower border of the clavicle to the junction of its outer and middle third; from this point it passes down over the anterior aspect of the shoulder to the medial side of the coracoid process, and extends down the arm following the medial border of the biceps for a short distance below the insertion of the pectoralis major. The triangular flap of skin and platysma between the upper longitudinal and infraclavicular incision is reflected outward, at which time the external jugular vein is met and divided between forceps. To gain a better exposure of the lower trunk of the plexus, the lateral tendon of insertion of the sternomastoid muscle may be divided close to its attachment to the clavicle. The deep fascia now being exposed is divided along the course of the skin incision and retracted laterally with its underlying cushion of fat. During this procedure the posterior belly of the omohyoid muscle is exposed and may be divided to obtain a more satisfactory exposure of the plexus. The prevertebral layer of the deep fascia is now exposed and the several transverse cervical vessels lying in front of it are ligated and divided. The prevertebral fascia is divided longitudinally, and the lateral border of the scalenus anticus muscle identified and exposed as it lies under the sternomastoid. The upper trunk of the plexus, formed by the anterior divisions of the fifth and sixth cervical nerves, will be found emerging from the lateral border of the scalenus anticus. These trunks lie upon the scalenus medius muscle, the fifth being found to emerge from behind the lateral border of the scalenus anticus, opposite the transverse process of the fifth cervical vertebra, and if followed downward, it will be found to unite with the sixth, forming the upper trunk of the plexus, which in turn divides into three branches, a smaller and lateral branch, the suprascapular nerve; an anterior branch (anterior division) uniting with the anterior division of the middle trunk to form the outer cord of the plexus; and a posterior branch (posterior division) uniting with the posterior divisions of the middle and lower trunks to form the posterior cord. If the

lesion extends below the upper trunk, involving its anterior or posterior division, it will be necessary to divide the clavicle in the exposure. This division of the clavicle should be done subperiosteally, in its middle third, with a Gigli saw. It is advisable to drill holes through the clavicle before its division, to facilitate its later approximation with wire.

When lesions involve the plexus in its lower or subclavicular region, the lower vertical limb of the "step-shaped" incision is carried down the arm as far as exposure seems necessary, usually some distance below the insertion of the pectoralis major muscle. The line of cleavage between the pectoralis major and deltoid is found and these muscles are separated and retracted; while

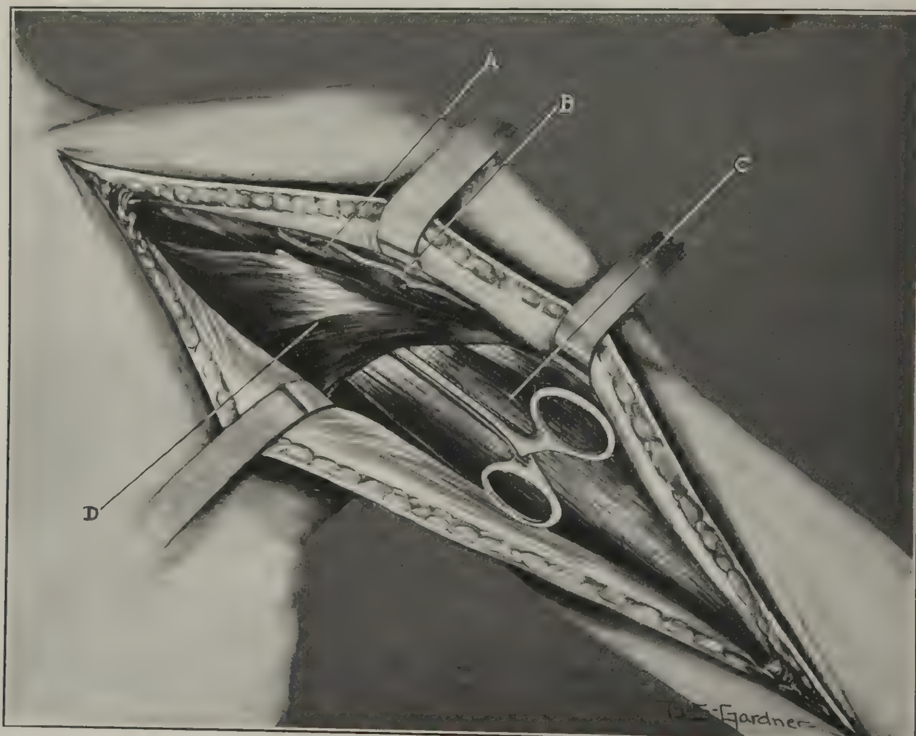

FIG. 165.—Infraclavicular exposure of brachial plexus. Line of cleavage deepened between pectoralis major and deltoid; forceps passed under pectoral tendon, preparatory to division. A, Deltoid; B, cephalic vein; C, biceps; D, pectoralis major

the adjacent fibers of these two muscles run parallel, the cephalic vein indicates the line of cleavage. In making this separation, the vein should be allowed to remain on the deltoid side and be carefully preserved, the line of cleavage being followed to the clavicle. To obtain exposure of the subclavicular portion of the plexus, the insertion of the pectoralis major into the humerus and of the pectoralis minor into the coracoid process may be divided, and these muscles retracted medially; after this retraction, the subpectoral fascia is divided, exposing below the neurovascular bundle. The lateral or medial end of the divided clavicle may be retracted by strips of heavy sterile bandage. The cords of the brachial plexus may now be identified by following upward their

terminal branches. The identification of the median nerve, which is the most superficial, is facilitated when followed upward, by its division into its respective outer and inner heads, in the fork of which will be found the axillary artery. If the outer head of the median is followed upward, it is found to join with the musculocutaneous nerve, forming the outer cord of the plexus. Following the inner head upward, it will be found to unite with the ulnar nerve and the internal cutanei, forming the inner cord of the plexus; in this manner both outer and inner cords are readily identified. In the axilla, the axillary artery is found lying immediately posterior to the median nerve. The loose connective tissue

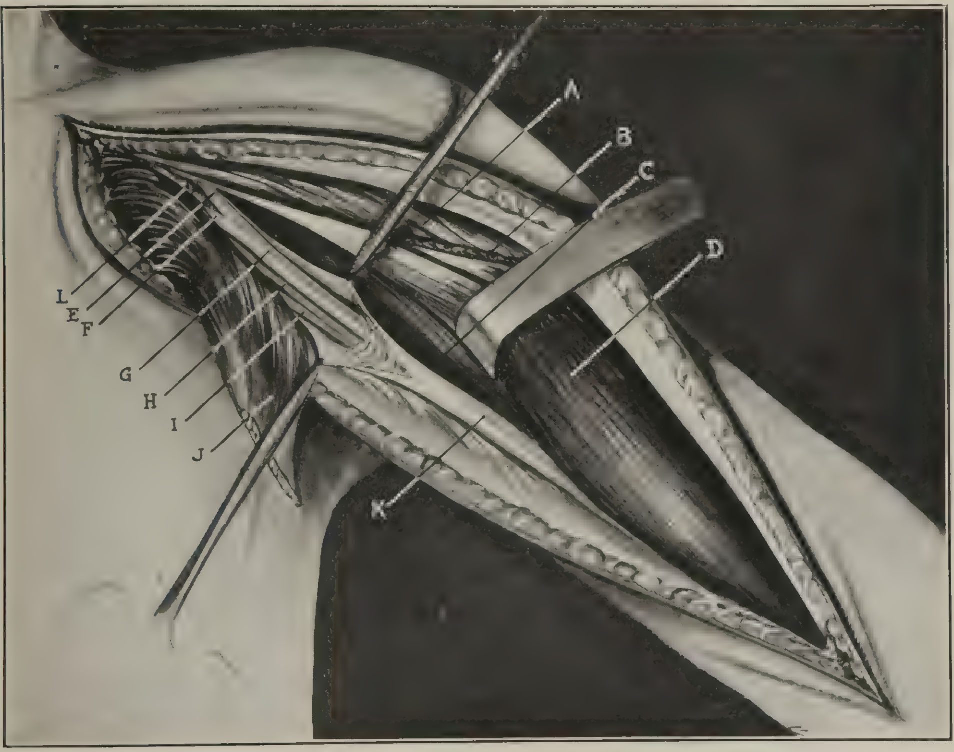

FIG. 166.—Infraclavicular exposure of brachial plexus; pectoralis major divided and reflected; neurovascular bundle exposed and sheath held open by forceps; biceps retracted laterally to facilitate exposure. A, Deltoid; B, pectoralis major tendon, divided; C, coracobrachialis; D, biceps; E, median, outer head; F, median, inner head; G, median nerve; H, ulnar nerve; I, internal cutaneous nerve; J, pectoralis major, reflected; K, neurovascular bundle; L, axillary artery

uniting these structures may be carefully separated, and posterior to the artery the musculospiral nerve is identified, which when followed upward is found to unite with the circumflex, and by this union to form the posterior cord. Probably the greatest difficulty in isolating the components of the neurovascular bundle below the clavicle is found in the bleeding from the division of numerous venous radicals. It is wise, therefore, early in dissection, to carefully isolate the axillary vein, beginning this dissection in the lower part of the incision. The presence of scar tissue greatly complicates the dissection of that portion of the plexus which lies in direct contact with the axillary artery and vein; if there is

evidence of an aneurysm, it is well to carefully expose the artery proximal to the aneurysm before its dissection is attempted, so that control of hemorrhage may be assured in case of accident. In isolating the axillary vessels in this region, caution should be used toward identifying and preserving the anterior thoracic nerves, the external of which in arising from the outer cord of the plexus passes over the artery, while the internal, arising from the inner cord passes under the artery; both branches usually pass over the axillary vein. If the preoperative report shows the pectoral muscles to be intact, the identification of the anterior thoracic nerves may be facilitated by electrical stimulation. These nerves

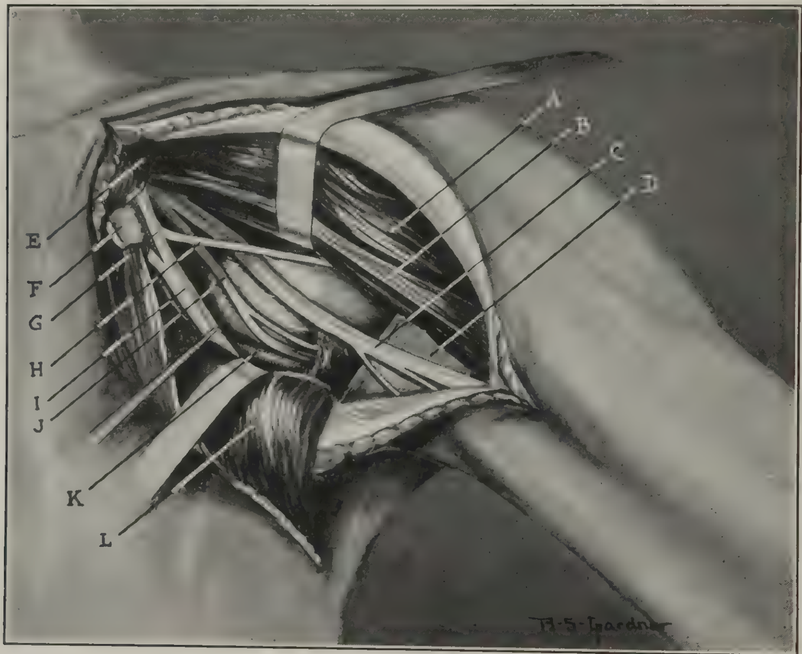

FIG. 167.—Infraclavicular exposure of brachial plexus. Median nerve retracted medially, exposing origin of outer head of the median and musculocutaneous nerve, behind which is seen the musculospiral nerve passing over the latissimus dorsi tendon, and the circumflex nerve accompanied by the circumflex artery, passing through the quadrilateral space in the posterior wall of the axilla. A, Deltoid; B, coracobrachialis; C, musculospiral nerve; D, latissimus dorsi tendon; E, coracoid process; F, pectoralis minor, tendon divided; G, median, outer head; H, musculocutaneous nerve; I, median nerve; J, circumflex nerve; K, circumflex artery; L, pectoralis major, tendon divided

enter the muscles on their under surface. In exposing the lower trunk of the plexus, both artery and vein must be well isolated and retracted downward. A mastery of the situation in difficult brachial plexus dissections can be assured only after thorough isolation of the adjacent vascular channels, and the preliminary attention given to this aspect of the procedure, though often time-consuming, is in the end a time-saving procedure. Occasionally the artery will be found so constricted by scar tissue as to render it a nonpulsating cord, which may closely resemble a nerve in appearance. In such cases the preliminary identification and exposure of the artery will avoid much trouble. It has occasionally been possible to restore pulsation in a compressed brachial

artery by the removal of constricting scar tissue. If this procedure fails to restore circulation, the vessel is probably obstructed by a thrombus. If collateral circulation is defective, arteriotomy may be attempted and the thrombus removed with the aid of a dull ring curette. After a free flow of blood has been obtained from both directions, the vessel may be closed with ordinary vascular sutures. When brachial plexus lesions are associated with irritative syndromes, the operator should never neglect the removal of scar tissue from the artery, and occasionally a decortication is indicated, after the method of Leriche. The importance of vascular lesions in this region, in the production of both painful and ischemic syndromes, can not be overestimated, and any effort devoted to the reconstruction or liberation of vascular channels is well worth while, even though collateral circulation seems to be adequate.

At this point it might be well to reiterate the necessity of physiologic preservation of the various plexus components and to emphasize the importance of conservatism in resection. Sutures of the plexus proper, because of distortion of normal nerve pattern, have given very unsatisfactory results; and unless the surgeon feels confident in his ability to preserve, at least to some degree, the original intraneural topography, far better results will probably attend a carefully executed external and internal neurolysis. The internal neurolysis, however, should be confined almost entirely to the resection of scar-invaded portions of the nerve sheath. Suture of the terminal divisions of the plexus is a far more satisfactory procedure in that it is possible to preserve in a large measure the original nerve pattern by the prevention of torsion during suture.[d]

THE CIRCUMFLEX NERVE

GENERAL ANATOMY

The circumflex nerve receives its fibers from the ventral division of the fifth and sixth cervical nerves through the posterior cord of the brachial plexus, in which it occupies a position lateral to the fibers forming the musculospiral, though within the same sheath. Near the outer border of the subscapularis the circumflex leaves the musculospiral to pass with the posterior circumflex vessels through a quadrilateral space in the posterior wall of the axilla, which is formed by the teres minor and subscapularis above, the teres major below, the long head of the triceps medially, and the humerus laterally. The nerve then winds around the surgical neck of the humerus posteriorly, and lying upon the under surface of the deltoid sends fibers to this muscle. In the region of the quadrilateral space the circumflex nerve divides in to an upper and a lower branch. The upper branch winds around the surgical neck of the humerus and supplies the bulk of the deltoid muscle; it also distributes cutaneous branches which pierce the muscle and supply the integument over the deltoid region. The lower branch gives off filaments to the teres minor and to the posterior fibers of the deltoid, after which it pierces the integument, which it supplies with sensation over the lower posterior deltoid region.

[d] The technique of physiologic approximation in suture of the terminal branches of the brachial plexus is considered in detail under the surgery of these respective individual nerves.

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SURGERY

AXILLARY EXPOSURE

Exposure of the circumflex nerve is obtained, as in low lesions of the brachial plexus, with the arm in outward rotation and marked abduction. The incision is made over the course of the neurovascular bundle from the middle of the clavicle to a few centimeters below the tendon of the pectoralis major. The deltoid is separated from the pectoralis major and the cleft between these muscles deepened to expose the deep pectoral fascia. (See figs. 165, 166, 167.) The pectoralis major is divided near its insertion into the humerus and reflected. The deep pectoral fascia is now divided to expose the neurovascular bundle. The median nerve and the axillary artery are identified and retracted medially, exposing the musculospiral nerve passing over the latissimus dorsi tendon. The musculospiral nerve is now followed upward to a point near the insertion of the pectoralis minor, where the circumflex will be found joining its lateral side to form the posterior cord of the brachial plexus. When thus identified the circumflex nerve may be followed around the medial side of the neck of the humerus to where it leaves the axilla by passing through the quadrilateral space to the dorsum of the arm.

DORSAL OR LATERAL EXPOSURE

Occasionally the circumflex nerve is injured after it has left the axilla in its passage around the surgical neck of the humerus. To approach lesions in this region a dorsal or lateral exposure is needed. The patient lies on his side with the arm acutely flexed across the chest, giving access to the posterior deltoid region. A longitudinal incision is now made approximating closely the dorsal border of the deltoid. This muscle is elevated and retracted forward. Retraction may be facilitated by elevation of the arm, relaxing the deltoid. Occasionally it will be found advisable to divide some of the posterior deltoid fibers. The circumflex nerve will be found hugging the neck of the humerus, as it emerges from the quadrilateral space, accompanied by the posterior circumflex artery and its venæ comites.

Isolated lesions of the circumflex nerve are comparatively rare, though deltoid paralysis is frequently associated with brachial plexus lesions, particularly those involving the upper trunk. Fortunately, the muscles of the shoulder girdle are supplied by branches given off from the brachial plexus at various points, so that a total paralysis of the shoulder is seldom encountered except in complete brachial plexus lesions. Individual nerves supplying the muscles of the shoulder and shoulder girdle run a relatively short course before breaking up into terminal branches to supply their respective muscles, so that their repair is as a rule exceedingly difficult; in fact their short course usually eliminates the possibility of effecting end-to-end approximation where a defect is present. Practically the only recourse the surgeon has when confronted with a serious defect in a nerve of short course is to resort to nerve grafting or viable transplants. This is particularly true in regard to isolated lesions of the circumflex nerve.

In irreparable lesions of the circumflex nerve and in those instances in which partial brachial plexus lesions are associated with deltoid paralysis and the loss of humeral abduction, arthrodesis of the shoulder joint gives perhaps more satisfactory results than any form of tendon transplantation if the scapular muscles have been preserved. The usefulness of this operation, however, depends entirely upon the preservation of scapular rotation.[e]

THE MUSCULOCUTANEOUS NERVE

GENERAL ANATOMY

The musculocutaneous nerve receives its fibers from the outer cord of the brachial plexus, in common with the outer head of the median below the clavicle. In the region of the neck of the humerus it leaves the neurovascular bundle and passes laterally between the two heads of the coracobrachialis to the under surface of the biceps, where it divides into a number of branches supplying this muscle and the brachialis anticus. Its sensory portion continues down the arm, and, emerging from between the biceps and the brachialis anticus, penetrates the deep fascia and pursues a subcutaneous course down the lateral side of the forearm, supplying the integument. As the musculocutaneous nerve enters its canal between the heads of the coracobrachialis, it gives off a branch to this muscle, which, though running directly with the musculocutaneous nerve and usually incorporated within its sheath, derives its fibers from the seventh cervical and is, to all intents and purposes, a special nerve as the musculocutaneous is derived solely from the fifth and sixth cervical.

Anatomic irregularities of the musculocutaneous nerve are too varied to be considered in detail; they consist principally of various communications with the median nerve. Occasionally a portion of the median nerve may follow the course of the musculocutaneous, and after this nerve gives off branches to the biceps and brachialis anticus the divergent fibers will again join the medial trunk; in other instances the branches to the biceps and brachialis anticus may spring directly from the median trunk. It is not uncommon to find various anomalous communications between the musculocutaneous and median nerves in various degrees. A consideration of these abnormalities will assist in explaining certain types of combined lesions which are at times inclined to be rather perplexing. The possibility of anatomic irregularities should always be considered when the clinical findings point to a combined partial musculocutaneous and median lesion.

SURGERY

Lesions of the musculocutaneous nerve may occur in any part of its course; in the upper portion of the arm, or in the axilla, it may be associated with concomitant lesions of the neurovascular bundle, though isolated lesions are

[e] The writer has recently observed a case of infantile paralysis in which the deltoid was completely paralyzed, though fairly effective abduction of the humerus by the short head of the biceps was possible. The possibility was immediately suggested of changing the point of origin of the short head of this muscle to a more lateral position by inserting it into the acromion process under the deltoid; this might also be reinforced by transplanting the long head of the triceps into this same position. Experimental work on the cadaver demonstrates the possibility of this procedure from an anatomic standpoint. Traction on these transposed muscles in a line corresponding to what would be their action after transposition results in forcible abduction of the arm. He has not had occasion to attempt this transplant clinically, but believes that it offers a possible means of humeral abduction in deltoid paralysis when bicipital and tricipital function is preserved.

by no means rare. If the nerve is injured in the lower third of the arm the motor fibers usually escape injury, its sensory portion alone being involved.

EXPOSURE

The exposure of the musculocutaneous nerve in the upper portion of the arm may be made as in lower plexus lesions. A long incision follows the medial border of the coracobrachialis, beginning a few centimeters below the clavicle and extending downward to the middle of the arm. The superficial fascia is divided, exposing the coracobrachialis. The line of cleavage between the pectoralis major and deltoid is deepened and the deep pectoral fascia exposed, care being taken to preserve the cephalic vein, which runs in the cleft between these muscles. It is usually necessary to divide the tendon of insertion of the pectoralis major to obtain access to the origin of the nerve. (See figs. 165, 166, 167.) The pectoralis major is retracted medially and the pectoral fascia covering the neurovascular bundle in the axilla divided, exposing the median nerve, which may be identified by electrical stimulation, though this is rarely necessary. If the nerve be followed upward, it will be found to divide into an inner and outer head, between which lies the axillary artery. Springing from the lateral side of the outer head will be found the musculocutaneous nerve, which abruptly leaves the neurovascular bundle and enters its canal between the two heads of the coracobrachialis.

When the lesion is below the branch to the coracobrachialis, the musculocutaneous nerve may be exposed without invading the axilla. A longitudinal incision is made over the upper portion of the biceps, and the line of cleavage between its two heads found and deepened. In the recess, the musculocutaneous nerve will be found lying upon the coracobrachialis. The nerve may now be followed along the under surface of the biceps by extending the line of cleavage between the long and short head downward through the substance of the muscle. In this way the motor branches may be adequately exposed. The motor branches spring from the lateral portion of the nerve trunk; the sensory from its medial side. A recognition of this fact will serve to facilitate physiologic approximation.

DEFECTS

Defects in the musculocutaneous nerve may be overcome to some extent by the relaxation obtained in flexing and adducting the arm over the chest. Defects not correctable in this manner, nor by stretching, will require grafting or a viable transplant. In closing the incision, if the tendon of the pectoralis major has been divided it should be carefully sutured with 20-day chromicized gut, and the arm maintained in flexion and adduction by strapping the hand to the opposite shoulder.

EXPOSURE OF THE SENSORY PORTION

Lesions involving the musculocutaneous nerve in the lower third of the arm are not accompanied by motor disability—in this region the nerve is entirely sensory. Occasionally, however, certain irritative lesions necessitate its exposure, when it may be sectioned or subjected to alcoholic injection. The

sensory portion of the nerve is occasionally utilized as material for autogenous grafts. Its exposure is made through an incision along the lateral surface of the arm corresponding to the medial border of the brachioradialis. The nerve will be found emerging from beneath the lateral border of the biceps, after which it pierces the deep fascia to become subcutaneous in the forearm. The biceps may be retracted medially, and the nerve followed upward beneath this muscle to the junction of the middle and lower third of the humerus, where it may be sectioned without injury to motor branches.

IRREPARABLE DEFECTS

Paralysis of the muscles supplied by the musculocutaneous nerve is not particularly disabling, as their function consists almost entirely in forearm flexion, which may be very satisfactorily accomplished in biceps paralysis by the brachioradialis, which muscle is supplied by the musculospiral nerve, though flexion by this muscle is usually associated with some degree of supination, which is corrected by action of the pronator radii teres, also capable of some forearm flexion. If an irreparable musculocutaneous lesion is combined with a permanent paralysis of the brachioradialis, pronator teres flexion of the elbow alone will be of little practical assistance, as its flexor power is weak and always associated with marked pronation. Under such conditions, apparently the only recourse is in arthrodesis of the elbow joint, immobilizing it in a position of flexion compatible with the needs of the individual.

MUSCULOSPIRAL NERVE

GENERAL ANATOMY

The musculospiral nerve is a continuation of the posterior cord of the brachial plexus, which in turn is formed by the posterior trunks of the anterior primary divisions of the fifth, sixth, seventh, and eighth cervical nerves. In the early part of its course it occupies a position dorsal to the axillary artery in the neurovascular bundle and pursues a somewhat spiral course posteriorly around the humeral shaft, and gains the lateral surface of the arm by penetrating the external intermuscular septum. In the lower part of the arm, it passes from a lateral to a ventral position at the elbow and there divides into two terminal branches, the radial and posterior interosseous nerves.

BRANCHES

In the axilla and on the inner side of the arm, which constitutes its *medial portion*, the musculospiral nerve gives off three branches: The internal cutaneous; a muscular branch to the long head of the triceps; and a muscular branch to the medial head of the triceps, sometimes called the ulnar collateral. In its *posterior* or *intratricipital portion* it gives off two external cutaneous branches, and muscular branches to the lateral and medial heads of the triceps. On the external surface of the arm, *lateral portion*, branches are given off to the brachioradialis, the extensor carpi radialis longior, and occasionally a small branch to the brachialis anticus.

Terminal branches.—The *radial* nerve passes down the radial side of the forearm, under cover of the brachioradialis muscle, to the dorsum of the hand; it is purely sensory and supplies sensation to the dorsum of the lower third of the forearm, hand, and fingers.

The *posterior interosseous* nerve carries chiefly motor fibers; passing under the brachioradialis muscle it pierces the supinator brevis, and in its passage through this muscle winds around the shaft of the radius to appear on the dorsum of the forearm. Before entering the supinator canal it gives off branches to the extensor carpi radialis brevior and the supinator brevis. Shortly after it emerges from the lower border of the supinator it fans out into a number of branches which supply the extensor communis digitorum, extensor carpi ulnaris, and extensor minimi digiti. A little lower in the forearm other branches are given off to the extensor ossis metacarpi pollicis, extensor longus and brevis pollicis, and extensor indicis.

SURGERY

From a standpoint of surgical accessibility, we shall consider the musculospiral nerve as having medial, dorsal, and lateroventral portions, with two terminal branches, the posterior interosseous and radial nerves.

MEDIAL PORTION

The medial portion of the musculospiral constitutes that part of the nerve trunk which lies medial to the humerus, extending from its origin in the axilla to where it crosses the long head of the triceps. In the upper part of its medial course the musculospiral nerve lies posterior to the axillary artery; in the lower part of the axilla it leaves the neurovascular bundle and, passing over the tendons of the teres major and latissimus dorsi, it begins its dorsal or intratricipital course by passing anterior to the long head of the triceps. From the medial portion of the musculospiral three branches are given off from the medial side of the nerve trunk—an internal cutaneous branch and two motor branches, one of which supplies the long head of the triceps, the other, known as the ulnar collateral, supplies the medial head of the triceps. These branches may be followed some distance up the nerve trunk, where they will be found to unite with two distinct bundles. The internal cutaneous branch unites with the bundle which in the dorsal portion of the nerve's course forms the external cutaneous. In other words, the sensory fibers contained in the internal and external cutaneous branches spring from a common bundle and separate from the parent trunk either combined or as separate branches. The identification of one sensory branch, if followed intraneurally, will serve to identify the other by their intraneural union. They may be identified distally by a careful dissection which will demonstrate their cutaneous termination. The two motor branches may be given off from the musculospiral trunk individually or, as occasionally happens, all the motor branches to the triceps will be found leaving the nerve trunk as a single large branch, later subdividing and forming the individual branches to its respective heads. More often the tricipital branches are loosely incorporated within the

musculospiral sheath, though they are distinctly individual and may possess a well-developed sheath of their own. The bundle containing the tricipital branches occupies a very definite position upon the medial side of the nerve, ventral to the cutaneous sensory bundle. The larger or lateral bundle constitutes that portion of the nerve which gives off branches to the supinator and extensors, ultimately terminating in the radial and posterior interosseous nerves. Lesions of the musculospiral nerve in its medial portion are often

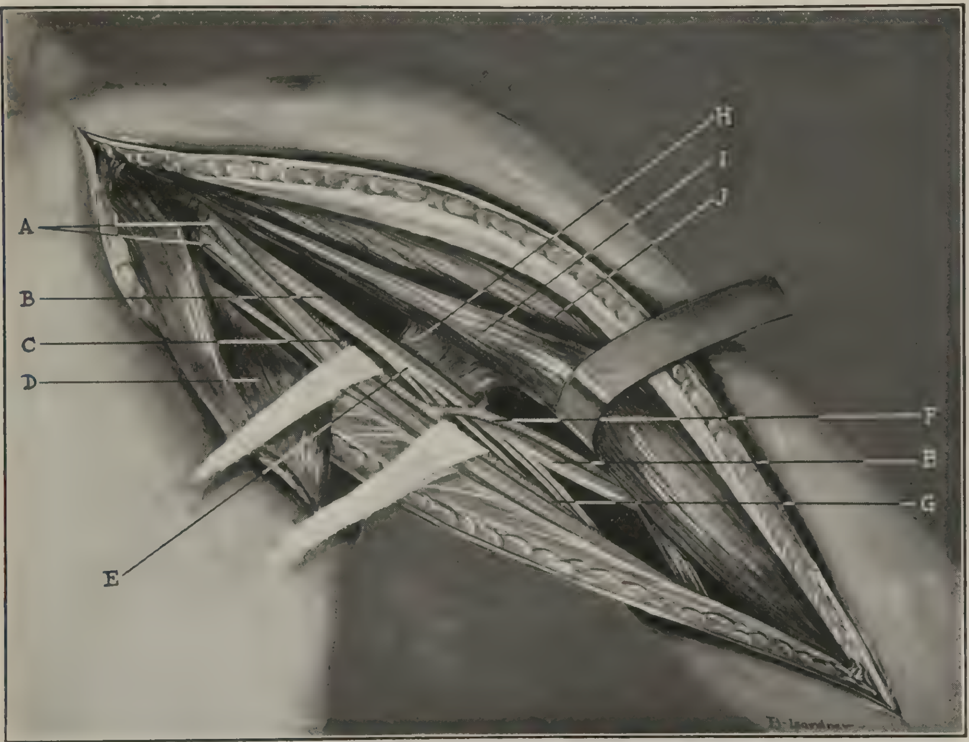

FIG. 168.—Exposure of medial portion of musculospiral nerve in the axilla and upper portion of the arm. Tendon of pectoralis major divided. Median and ulnar nerves with brachial artery, retracted medially, exposing musculospiral nerve and superior profunda artery, as they cross the tendon of the latissimus dorsi and long head of the triceps, entering their posterior humeral course. The branches of the medial portion of the musculospiral are shown springing from the medial aspect of the musculospiral trunk. A, Median nerve, outer and inner head; B, musculospiral nerve; C, axillary artery; D, pectoralis major, reflected; E, musculospiral medial branches; F, superior profunda artery; G, brachial artery; H, latissimus dorsi tendon; I, coracobrachialis; J, deltoid; K, Pectoralis minor tendon

combined lesions, corresponding to terminal plexus types, and frequently are associated with vascular injury.

The method of exposure of the musculospiral nerve in its upper medial portion within the axilla is the same as that used in infraclavicular plexus lesions. Its lower medial portion is exposed through a straight incision, extending from the base of the axilla to the middle of the humerus, in a line corresponding to the medial edge of the coracobrachialis. The deep fascia is divided, exposing the neurovascular bundle; by ligating a few branches of the brachial artery and their accompanying veins, the contents of the neurovascular

bundle may be retracted medially, and the musculospiral nerve located as it crosses the latissimus dorsi tendon, accompanied by the superior profunda artery; or it may be located before it leaves the neurovascular bundle, where it lies behind the brachial artery. Its cutaneous and motor branches should now be identified as they leave the nerve trunk from its medial surface. The motor branches are identified readily by following them to a muscle termination, while the internal cutaneous branch will be found to penetrate the deep

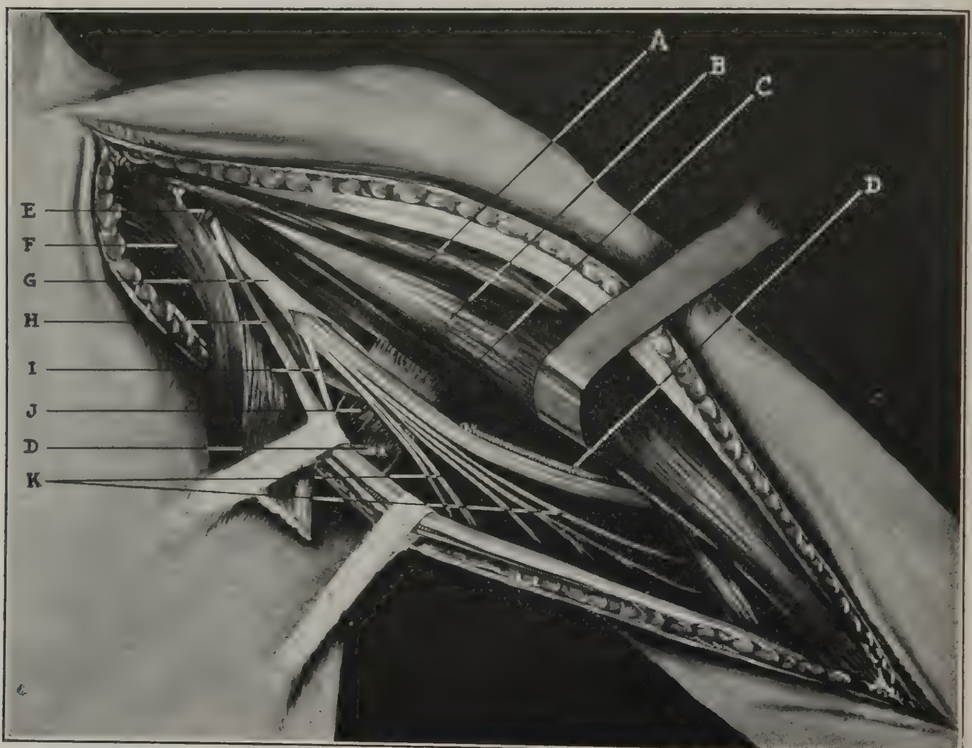

FIG. 169.—Exposure of median portion and internal part of posterior portion of musculospiral trunk through medial incision. Contents of neurovascular bundle retracted medially; superior profunda artery ligated; complete exposure of tricipital branches; intraneural dissection, showing their origin from medial side of the musculospiral trunk. A, Deltoid; B, biceps; C, coracobrachialis; D, superior profunda artery, ligated; E, pectoralis minor tendon; F, pectoralis major, reflected; G, musculospiral nerve; H, median nerve; I, internal cutaneous branch; J, latissimus dorsi tendon; K, tricipital branches

fascia to assume a cutaneous position. Retraction of the long head of the triceps will permit very satisfactory exposure of the nerve on the medial side of its intratricipital course, where it will be found passing lateral to the medial head of the triceps as it enters the musculospiral groove on the posterior surface of the humerus. Division of a few of the internal fibers of the medial head of the triceps will permit adequate exposure of the nerve through most of its posterior course. This medial incision is also frequently required to gain access to the nerve in its dorsal position.

DORSAL PORTION

The dorsal or intratricipital portion of the musculospiral is that part of the nerve which lies posterior to the humerus and is covered by the triceps. The nerve enters the posterior surface of the arm by passing anterior to the long head of the triceps shortly after it has left the neurovascular bundle. In its dorsal course it first lies on the ventral surface of the long head of the triceps; then occupying a position in direct contact with the humerus it passes through the musculospiral groove, just above the origin of the medial head of the triceps and below the origin of the lateral head of the triceps, which latter covers the nerve. Having pursued a somewhat spiral course around the humeral shaft, the nerve emerges from its dorsal position by penetrating the external intermuscular septum to appear on the lateral aspect of the arm. In its dorsal course, the nerve is accompanied by the superior profunda artery and its accompanying vein, which lie lateral to the nerve. The superior profunda artery, upon reaching the external intermuscular septum, divides into two branches, the smaller of which penetrates the intermuscular septum and accompanies the musculospiral nerve; the larger branch follows along the posterior surface of the intermuscular septum to the elbow. In its dorsal portion the musculospiral nerve gives off branches to the lateral and medial heads of the triceps. These branches almost invariably lie on the medial side of the nerve, and may be followed up the nerve trunk as individual branches or as a single bundle into the axilla. The external cutaneous nerve, though given off with the internal cutaneous from the medial side of the musculospiral nerve, crosses the parent trunk and follows its lateral surface with the profunda artery where it divides into a superior and an inferior cutaneous branch. These cutaneous branches do not penetrate the external intermuscular septum, though the inferior branch passes over it and becomes cutaneous near the elbow.

The nerve in this region, occupying a position in direct contact with the humerus, is frequently injured in fractures of the middle third. It may be completely crushed by the trauma producing the fracture, though probably it is more often traumatized and stretched by the bone fragments at the time of injury or during efforts at fracture reduction. Occasionally it is found compressed or completely buried in the callus of an old fracture.

Exposure of the musculospiral nerve in its dorsal position may be accomplished by several methods:

A. *Dorsal longitudinal incision.*—An incision beginning about 7 centimeters below the acromial process is carried down the middle of the posterior surface of the arm to the junction of its lower and middle thirds, in line with the olecranon. The deep fascia is incised; and the cleavage between the long and lateral heads of the triceps found and deepened until the aponeurosis of their ventral surface is encountered. This aponeurosis is then carefully divided to prevent injury to the musculospiral nerve and its branches, which lie directly on its ventral surface. In separating the long and lateral heads of the triceps upward, the posterior fibers of the deltoid are retracted laterally, some of which may require division. Retraction of the tricipital heads will give a satisfactory though rather limited exposure of the musculospiral groove

and its contents. When extensive scar tissue is present, the dorsal incision should be supplemented by a lateral incision, exposing the nerve as it emerges on the lateral surface of the arm, after penetrating the external intermuscular septum. The nerve is identified at this point and the lateral head of the triceps separated from its attachment to the septum and retracted dorsally, exposing the lateral portion of the musculospiral groove. Occasionally it will be found necessary to divide the lateral head of the triceps and in such instances the division should be made as high as possible to avoid injury to its nerve supply. A piece of tape passed under the lateral head of the triceps between these two incisions will often permit sufficient retraction of the muscle from the humerus to expose the nerve throughout its course in the musculospiral groove. In attempting retraction or division of the lateral head of the triceps through the combined dorsolateral incisions, the greatest care should be used to prevent injury to the tricipital branches, which at first should be identified and isolated in the upper portion of their course. The operator frequently experiences difficulty in this dissection, due to injury of the superior profunda artery and veins. It is expedient, therefore, early in the exposure, to secure primary ligation of the artery in the upper part of the wound and ligation of the veins dorsal to the external intermuscular septum.

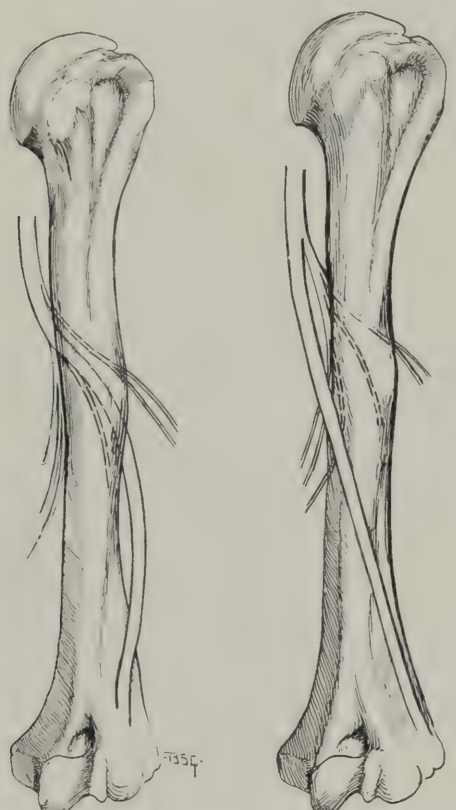

FIG. 170.—Showing course of musculospiral nerve, and relation of branches to triceps, as it passes behind humerus in musculospiral groove. Preservation of branches in transposing nerve to anterior position. (Ney. *Annals of Surgery*, 1921)

B. *Exposure of the dorsal portion of the musculospiral by a combined medial and lateral incision.*—The medial portion of the musculospiral groove may be readily approached through the low incision described for exposure of the musculospiral in the lower part of its medial portion, by retracting medially the neurovascular bundle, and dorsally the long head of the triceps. This approach will also facilitate control of the profunda artery and the identification and isolation of the tricipital branches. This medial exposure is supplemented with the lateral incision, through which the musculospiral nerve is identified as it penetrates the external intermuscular septum, and the attachment of the lateral tricipital fibers freed from this structure. In this procedure the long and lateral heads of the triceps are retracted from the humerus, exposing the nerve throughout its intratricipital course. The advantage of this method is obvious; it gives a complete exposure of the nerve and all its tricipi-

tal branches; it permits of satisfactory hemostasis, in that the profunda artery may be secured above and the veins below; and in the presence of extensive continuity defects, it permits transposition of the nerve to an antebrachial position by allowing mobilization of the nerve trunk, without endangering its branches and without additional incisions.

The proximity of the musculospiral nerve to the humerus in its dorsal course frequently calls for the preparation of a new nerve bed. When this is necessitated, because of extensive callus or scar tissue, the nerve may be separated from direct contact with the bone by changing its course from the musculospiral groove to a lower position where it is made to pass behind the medial head of the triceps. This procedure requires mobilization of the nerve through its lateral portion, and low separation of the lateral head of the triceps from the external intermuscular septum, permitting the nerve to follow a lower dorsal course between the medial and lateral heads of the triceps. When extensive bone callus or scar tissue involves the posterior surface of the humerus and the tricipital heads, recourse should be had to an antebrachial transposition, in which the nerve is directed anterior to the humerus, between the biceps and the brachialis anticus.

VENTROLATERAL PORTION

The ventrolateral portion of the musculospiral nerve constitutes that portion of the nerve which lies lateral and ventral to the humerus on the external aspect of the arm, beginning at the external intermuscular septum and terminating in front of the external humeral condyle, where it bifurcates into its two terminal branches. In its ventrolateral course, in passing down the lower third of the arm, the nerve is deeply placed between the brachioradialis and brachialis anticus. In the region of the external humeral condyle, the nerve is covered by the brachioradialis and rests upon the brachialis anticus. This portion of the nerve gives off a branch to the brachioradialis shortly after entering the lateral surface of the arm. A little lower, a branch is given off to the extensor carpi radialis longior. These motor branches emerge from the lateral side of the musculospiral trunk, the branch to the brachioradialis being the most ventral of the lateral group of motor fibers. Immediately behind this branch lies the bundle containing the fibers to the carpal extensors. The branch to the extensor carpi radialis brevior is occasionally given off with the branch to the long carpal extensor, though more frequently it leaves the nerve trunk from its terminal posterior interosseous division. It has, however, a long intraneural course, and if followed up the nerve will be found to spring from a bundle common to both radial extensors.

Injuries to the musculospiral in this region are probably more often encountered in military surgery than injuries to any other nerve. It is a common complication of fractures of the lower third of the humerus, and in civil life the frequency of its occurrence is approximated only by lesions of the ulnar in the region of the internal epicondyle. In simple fractures the trauma to the nerve consists usually in stretching, or bruising against bone fragments; in the absence of an open wound it is rarely divided. Paralysis of the musculo-

spiral nerve by pressure has frequently been observed following the use of a tourniquet, and surgeons who insist upon its use should remember this possibility and endeavor to protect the musculospiral region by properly placed pads.

Exposure of the lateroventral portion of the musculospiral is made through a longitudinal incision, extending from the insertion of the deltoid to a point midway between the biceps tendon and the external condyle of the humerus. In the lower part of the incision the cephalic vein is divided between forceps. In the upper part of the incision, the lateral cutaneous branches may be met, and, if necessary, sacrificed with impunity. The line of cleavage between the brachioradialis laterally and the biceps and brachialis anticus medially is identified and these muscles retracted. In the cleft, deeply placed, the musculospiral nerve is found accompanied by a small terminal branch of the superior profunda artery. Occasionally, the inferior external cutaneous branch, which

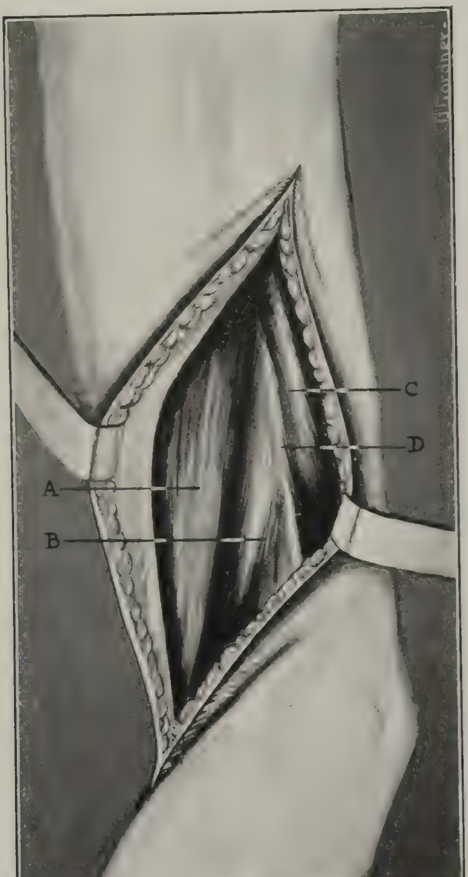

FIG. 171.—Landmarks for exposure of musculospiral nerve in its latero-ventral aspect, showing external intermuscular septum, from the ventral side of which arises fibers of the brachioradialis, and from its dorsal surface, fibers of the lateral head of triceps. Musculospiral nerve is exposed by deepening the cleft between brachioradialis and biceps which lies ventral to the latter muscle. A, Biceps; B, brachioradialis; C, triceps, lateral head; D, external intermuscular septum

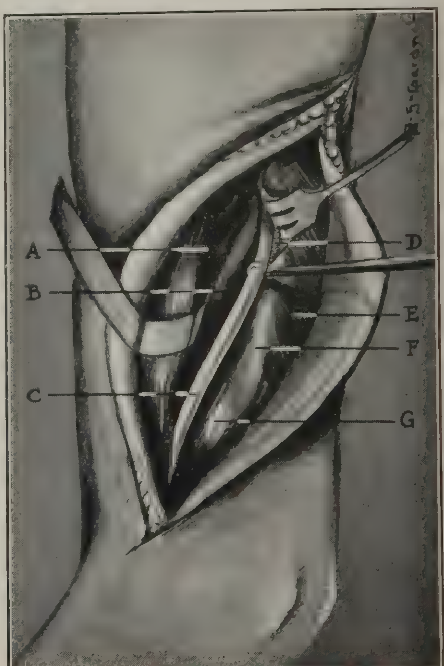

FIG. 172.—Musculospiral nerve, latero-ventral aspect, showing emergence on lateral surface of arm, after penetrating external intermuscular septum. A, Biceps; B, brachialis anticus; C, musculospiral nerve; D, superior profunda artery; E, triceps, lateral head; F, external intermuscular septum; G, brachioradialis

is of fairly large size, will be found passing along the external intermuscular septum and should not be mistaken for the musculospiral trunk. It will often serve as a guide, if followed upward, in locating the musculospiral.[f]

The musculospiral trunk should be isolated above the lesion to facilitate branch identification and preservation, even though it be necessary to invade its dorsal or intratricipital portion. In following the nerve downward, between

FIG. 173.—Musculospiral nerve, postero-lateral aspect; lateral head of triceps divided close to attachment to external intermuscular septum, exposing nerve in lateral aspect of its dorsal course in musculospiral groove. A, Musculospiral nerve; B, triceps, lateral head, divided; C, biceps; D, brachialis anticus; E, external intermuscular septum; F, brachioradialis

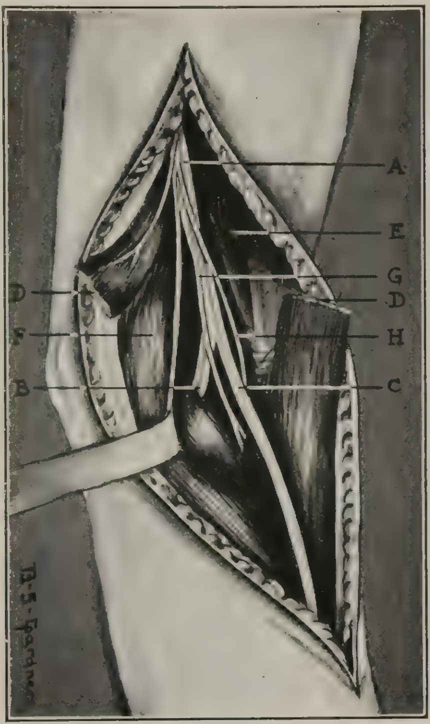

FIG. 174.—Musculospiral nerve at elbow, showing terminal posterior interosseous and radial divisions. Brachioradialis divided. Intraneural dissection of branches shows them springing from lateral side of musculospiral trunk. Radial nerve is given off from ventro-medial aspect of musculospiral trunk; posterior interosseous nerve arises from dorso-lateral portion of trunk. A, Musculospiral nerve; B, posterior interosseous nerve; C, radial nerve; D, brachioradialis, divided; E, brachialis anticus; F, extensor carpi radialis longior; G, branch to extensor carpi radialis brevior

the brachioradialis and the brachialis anticus, extreme care should be used in preserving motor branches. In the upper part of this region, if the circumference of the musculospiral nerve be divided into a lateral, posterior, and medial sector, the lateral sector will be found to contain motor fibers to the brachioradialis and carpal extensors, the posterior sector will contain those

[f] The writer has on one occasion reoperated a case of musculospiral paralysis which failed to regenerate, and found the proximal end of the musculospiral anastomosed to the distal segment of this branch; in the original operation, the surgeon had apparently mistaken the cutaneous branch for the musculospiral trunk.

motor fibers which eventually form the posterior interosseous nerve, and the medial sector will contain sensory fibers ultimately forming the radial terminal division.

In the region of the external condyle, the musculospiral nerve lies upon the brachialis anticus and under cover of the brachioradialis. Strong lateral retraction of the latter muscle will expose the nerve where its two terminal branches may be identified—the posterior interosseous, arising from its lateral and posterior sector; and the radial, arising from its medial sector.

INTEROSSEOUS NERVES

The posterior interosseous nerve, containing mostly motor fibers, innervates the supinator, extensor carpi ulnaris, and extensors to the fingers and thumb, and it constitutes the terminal motor portion of the musculospiral trunk. After its separation from the radial nerve on the undersurface of the brachioradialis, it passes under the long and short carpal extensors and swings around the shaft of the radius to the dorsum of the forearm, by passing through a a canal in the substance of the supinator brevis muscle, in a line almost at right angles to the direction of the supinator fibers. After emerging from the lower border of the supinator on the dorsal surface of the forearm, the posterior interosseous nerve fans out into a leash of branches supplying the extensors of the fingers and thumb.

Lesions of the posterior interosseous nerve below the upper third of the forearm are rarely amenable to suture, due to the breaking up of the nerve into a series of small branches. Suture may be effected, as a rule, only when the nerve is found injured in the substance of the supinator or proximal to that muscle. Occasionally, however, it will be found possible to complete a satisfactory neurolysis in the region where the nerve breaks up below the supinator. When it is found impossible to restore the nerve supply to the digital extensors, it is advisable to complete the operation by tendon transplantation.

Exposure of the posterior interosseous nerve.—A longitudinal incision is made down the posterior surface of the forearm in the midline, beginning at a point two centimeters medial to the external condyle and ending in the middle third of the forearm. The deep fascia is divided and the line of cleavage between the extensor carpi radialis brevior and the extensor communis digitorum identified. These muscles are separated up to their common origin at the external condyle and retracted, exposing the fascia covering the supinator brevis muscle below. The course of the posterior interosseous nerve through the supinator is at almost right angles to its fibers, and its position may often be identified by palpation. Failing in this, separation of the muscle fibers in their line of cleavage will usually serve to locate the nerve, which is greatly flattened as it passes around the shaft of the radius. Exposure of the lower border of the supinator will also aid in its identification, as it emerges from this muscle.

The posterior interosseous nerve may be completely exposed by dividing the superficial fibers of the supinator covering the nerve; by flexing the forearm and retracting the radial carpal extensors and the brachioradialis, it may be followed to its junction with the radial. Extreme care, however,

should be used in avoiding the branches supplying the supinator, which are usually given off just before the nerve enters this muscle or during its passage through the muscle. Lesions within the supinator region of the posterior interosseous as a rule may be satisfactorily exposed through the dorsal forearm incision; but when the lesion is located in its presupinator portion, it is best exposed by separating the long radial extensor from the brachioradialis

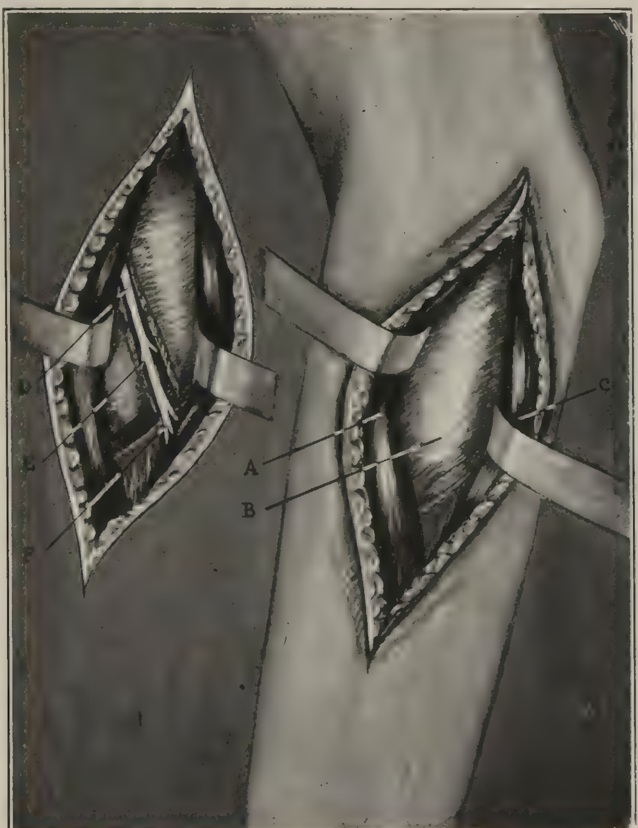

FIG. 175. -A, Supinator brevis exposed by separating extensor carpi radialis brevior and extensor longus digitorum. B, Intrasupinator portion of posterior interosseous nerve exposed by dividing superficial fibers of supinator brevis. Branches to supinator shown leaving the nerve in the substance of the muscle. At lower border of supinator, posterior interosseous fans out into a leash of branches, below which repair is difficult. A, Extensor carpi radialis brevior; B, supinator brevis; C, extensor longus digitorum; D, posterior interosseous nerve; E, branches to supinator; F, posterior interosseous, below supinator

through a slightly more anterior incision, corresponding to a continuation of of the lateral musculospiral incision to the dorsum of the forearm. In exposing that portion of the nerve lying between its origin and the supinator (presupinator portion), great care must be utilized to prevent injuring the branch to the short carpal extensor, which is given off from the anterior surface of the nerve. It is usually of sufficient size to permit of separate suture, and efforts should always be made toward its conservation or repair.

RADIAL NERVE

The radial nerve constitutes the terminal sensory division of the musculospiral trunk; it first lies under the brachioradialis and upon the brachialis anticus, medial to the posterior interosseous. It progresses down the ventral and radial surface of the forearm under cover of the brachioradialis muscle. At the junction of the upper and middle third of the forearm it is joined by the radial artery, which lies on its medial side and accompanies it through the middle third of the forearm. At the beginning of the lower third it leaves the artery and passes under the tendon of the brachioradialis to enter the posterior surface of the forearm, where it supplies sensation to the dorsum of the wrist, hand, and fingers.

SURGERY

The radial nerve, being entirely sensory, is seldom exposed for repair. It is, however, occasionally used as a graft for filling continuity defects in other nerves, because of its fairly large size and the minimal degree of disability resulting from its sacrifice; when used for grafts, its uppermost portion is usually selected.

Exposure of the radial nerve may be accomplished through an incision beginning just above the bend of the elbow, midway between the external humeral condyle and the biceps tendon, and carried longitudinally down the radial surface of the forearm as far as necessary, paralleling the medial border of the brachioradialis. The deep fascia is divided and the medial edge of the brachioradialis exposed and retracted. The radial nerve may be identified passing along the under surface of this muscle, and may be followed up to a point where it joins the posterior interosseous to form the musculospiral trunk.

CONTINUITY DEFECTS

The correction of defects in the continuity of the musculospiral nerve differs in no way from those methods used in overcoming defects in other nerves except in transposition, when the musculospiral nerve is changed from its spiral course around the posterior aspect of the humerus to the more direct ventral course anterior to the humerus, where it is made to pass between the biceps and the brachialis anticus, following a course similar to that taken by the musculocutaneous nerve.

TECHNIQUE OF MUSCULOSPIRAL TRANSPOSITION

The musculospiral nerve is exposed in its medial portion (see technique of low exposure of the medial portion of the musculospiral nerve, p. 997); the branches to the triceps are identified by retraction of the triceps and mobilized from the musculospiral trunk.

The musculospiral is exposed and freely mobilized from the external intermuscular septum to its terminal branches, using care to prevent injury to branches in this region. The lateral head of the triceps is separated from its attachment to the external intermuscular septum and carefully separated from the humerus along the course of the musculospiral groove. A piece of tape is passed through the tunnel between the lateral and medial incisions, and the

triceps by this means retracted from the bone, completely exposing the nerve. It is important that the ends of the nerve be marked with identification sutures before the nerve trunk has been rotated during mobilization.

A second tunnel is made connecting the lateroventral incision with the medial, by identifying the medial and lateral borders of the biceps and by blunt dissection, separating this muscle from the underlying brachialis anticus, following the line of cleavage between these muscles and using care to prevent injury to the musculocutaneous nerve.

The musculospiral nerve is now drawn from its intratricipital course and made to pass in as direct a line as possible from the neurovascular bundle below the axilla to its position medial to the external humeral condyle below the biceps. After transposition, the surgeon may avail himself of flexion-relaxation to assist in overcoming any part of a defect not corrected by the transposition. It is particularly important to prevent torsion of the nerve trunk during suture, and the early placing of accurate identification sutures is essential as a guide for restoring physiologic alignment.

Physiologic Approximation of the Musculospiral and its Terminal Divisions.

The musculospiral nerve, by virtue of its motor branches, lends itself to physiologic approximation more readily than any other nerve. While the prevention of torsion is perhaps best accomplished through effectively placed identification sutures, there are certain instances, particularly in secondary sutures, where this means of identification can not be relied upon.

In effecting suture of the medial portion of the musculospiral nerve, identification of tricipital branches will immediately demonstrate the medial side of the nerve. In its posterior position, the tricipital branches likewise indicate the medial side of the nerve, though the lower branches to the triceps occupy a more dorsal position. In the region of the external intermuscular septum, the nerve occupies a rather fixed position, which is not readily disturbed by trauma; in this position, the motor fibers lie in the lateral portion of the trunk, the sensory fibers to the medial side. The nerve in its course around the humerus, first contains its motor fibers in its medial side. Later, in the musculospiral groove, they become posterior, the sensory fibers being in contact with the humerus. In the region of the external intermuscular septum the nerve presents a different arrangement, due to a slight natural torsion in its spiral course. In its lateroventral position, the motor bundles lie on the lateral and dorsal surface of the nerve, whence springs its motor branches and which ultimately terminate in the posterior interosseous nerve. The sensory portion of the trunk, having a more medial and anterior position, terminates in the radial nerve. By keeping these facts in mind, torsion may be prevented to a great degree in lateroventral sutures of the musculospiral; the motor portion of the trunk being readily identified by the position of its motor branches, also by the posterior interosseous nerve, springing from its lateral and somewhat dorsal quadrant; the sensory portion of the nerve being identified by the absence of branches and by the position of the radial nerve. To make topographical matching still more accurate, it should be remembered that the branch to the brachioradialis occupies the most ventral motor position. More

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laterally in the nerve trunk will be found the bundle sending fibers to the long and short radial extensors. That portion of the nerve immediately behind these funiculi ultimately forms the posterior interosseous trunk.

Torsion in the posterior interosseous nerve is not so serious an eventuality as in mixed nerves, because most of the nerve trunk is composed of motor fibers. In the supinator region, the nerve is greatly flattened and its fixation so secure that reasonable care should prevent torsion.

If doubt exists in suturing the musculospiral nerve as to the location of its sensory segment, recourse should be had to the electro-anatomic method, in which the sheath of the upper segment of the nerve is opened and the bundles subjected to very weak faradic stimulation. Stimulation of the sensory bundles will elicit a sensation of tingling or pain localized in their cutaneous distribution, while stimulation of a motor bundle will demonstrate the presence of myo-sensory fibers. (See general technique, p. 951.)

Secondary Suture of the Musculospiral Nerve.

Surgery of the musculospiral nerve has perhaps given more satisfactory end results than that of any other nerve, which may be attributed to the following facts:

1. The greater number of injuries occur in its lateroventral portion or in the lateral part of its dorsal portion, which leaves a comparatively short distance for the neuraxons to regenerate to reach their ultimate muscle termination. This feature, facilitating an earlier restoration of neuromuscular junctions saves the muscles from that extreme degree of degeneration encountered when denervated for a long period of time—a condition which can not be avoided in nerves injured at a great distance from the muscles they supply.

2. The extensor muscles, supplied by the musculospiral are relatively large in bulk and the chance of receiving a greater number of regenerated nerve fibers is thereby enhanced.

3. The extensor function of the wrist is accomplished by three extensor muscles, supplemented by the common extensors of the fingers, so that defects in one or more muscles may not seriously affect extensor function.

4. Extensor paralysis of the wrist is more generally and earlier recognized, and lends itself more readily to splinting than any other types of paralysis; it is thereby often saved from prolonged muscle stretching.

A careful examination of regenerating musculospiral lesions will demonstrate that, though the functional end results of musculospiral sutures are more satisfactory than any other nerve, from a standpoint of individual muscle function, defective regeneration is present in the great majority of musculospiral sutures, and that those muscles which have a relatively small bulk and which are innervated at some distance from the point of lesion, present the same degree of defective regeneration as observed in other nerves. After musculospiral suture, radial carpal extension and brachioradialis action are commonly restored. Less frequently, however, do we observe a return of function in the ulnar carpal extensor, and in the extensor communis digitorum, while in the extensors of the thumb, index, and little fingers function is frequently not regained. Undoubtedly, they enter into that extreme degree of muscle degeneration common to muscles of small bulk, long denervated.

Indications for Reoperation

Before the musculospiral nerve is subjected to secondary surgical intervention, certain facts regarding the failure of regeneration should be definitely determined:

1. *The absence of neuraxon regeneration beyond the point of suture, or defective or retarded regeneration through the distal segment.*—Tinel's sign, elicited with the same degree of intensity below the suture line, as at the suture line, indicates successful neuraxon regeneration. The downward progression at the rate of 1 inch per month, of the point at which formication can be elicited indicates that regeneration is not retarded, at least in so far as sensory fibers are concerned. A complete absence or a greatly diminished reaction of formication below the suture line indicates absence or defective neuraxon regeneration. After three months, a failure to elicit formication below the suture line suggests the absence of regeneration, particularly if this reaction is intense at the suture line, though it may mean only a delay in regeneration. A decision, therefore, should not be definitely made until a lapse of six months, at which time absent or greatly diminished formication in the distal segment of the nerve should call for secondary surgical intervention.

2. *Torsion of the nerve trunk resulting in the physiologic misplacement of fibers* is another common cause for defective musculospiral regeneration. The writer has reoperated a case in which at the original operation, the operator failed to identify the posterior interosseous terminal division of the nerve and united the musculospiral trunk wholly to its radial terminal division, the lesion being in the region of the internal condyle. In this case, the long carpal extensor branch was individually divided and not repaired, leaving a complete musculospiral paralysis below the supinator. Frequently, however, torsion has occurred during the primary suture and the radial sensory fibers have passed down the posterior interosseous nerve and the motor fibers to the radial nerve: obviously, the misdirected fibers are physiologically lost. This misdirection of fibers may occur to any degree and the advisability of secondary operation for its correction depends entirely upon the extent of misplacement and the degree of motor function regained. We must again rely upon Tinel's sign to determine the position of sensory fibers, and the musculospiral nerve in its terminal divisions readily lends itself to convey this information. Percussion of the nerve trunk below the suture line may give an intense reaction of formication, but when percussion of the radial nerve (which normally should convey these sensory fibers) elicits no tingling or only a slight reaction, the sensory fibers are absent and have probably been misdirected, if sufficient time has been allowed for them to reach the radial trunk. Percussion of the posterior interosseous on the dorsum of the forearm in the region of the supinator will normally give little or no tingling, as it contains mostly motor fibers. When there has been any great misdirection of radial fibers through the posterior interosseous nerve, its percussion will elicit intense tingling which is localized on the dorsum of the hand. This localization of tingling is important as it demonstrates that the sensory fibers in the posterior interosseous nerve are definitely radial in origin, it being remembered that in percussing the musculospiral or the posterior interosseous nerve, the examiner may elicit reactions in the external cutaneous

branch of the musculospiral, in which event the tingling sensation would be localized along the dorsal portion of the forearm and not the hand. Frequently, the presence of sensory fibers in the extensor muscles on the back of the forearm may be demonstrated by pressure on their atrophied bellies, this pressure eliciting a strong formication.

Regenerative defects, due to misdirection of fibers are unfortunate, in that the muscles have been allowed to reach an extreme degree of degeneration because of their greatly delayed reinnervation. If muscle degeneration is extreme, recourse must be had to tendon transplantation for correction of the motor defect. If, however, these muscles have been preserved and still respond to galvanic stimulation, secondary suture should be attempted for the purpose of correcting torsion. In the secondary operation, the surgeon must not be guided by anatomically placed identification sutures, but the motor side of each segment of the nerve trunk should be identified by the position of its branches or by the electro-anatomic method, and the nerve resutured in a manner which will approximate motor segment to motor segment. (See physiologic approximation of the musculospiral nerve, p. 1007.)

3. *Defective musculospiral regeneration due to extensive muscular degeneration.* Percussion of the musculospiral trunk has demonstrated by Tinel's sign the progressive downgrowth of neuraxons: percussion of the radial and posterior interosseous nerves reveals the presence of radial sensory fibers in the former and their absence in the latter; therefore, neuraxon regeneration has probably not been seriously impeded or misdirected. The return of deep sensibility in the muscles suggests regeneration of myo-sensory fibers which normally accompany motor fibers, and their presence probably indicates the regeneration of motor fibers to the muscles. The clinical degenerative phenomena continue to persist in the paralyzed muscles (complete loss of electrical and mechanical irritability and a total absence of voluntary motion, with extreme atrophy). Instances of this kind are by no means rare and are usually due to prolonged denervation and ischemia. In this type of regenerative failure, secondary operations upon the nerve are absolutely useless and contraindicated. In some cases, time may effect improvement, particularly if accompanied with energetic treatment to improve circulation and muscle nutrition. In most of these instances, the only hope of restoring extensor function to the wrist and fingers lies in tendon transplantation.

TENDON TRANSPLANTATION FOR MUSCULOSPIRAL PARALYSIS

Probably no other tendon transplants give results so satisfactory as those devised for the drop wrist and fingers in musculospiral paralysis.

In complete irreparable defects of the musculospiral nerve, transplantation is indicated for three conditions, namely, wrist-drop, finger-drop, and thumb-drop. In low lesions (posterior interosseous), carpal extension may be preserved, transplantation being required only for the digitis. This may be the case also in defective musculospiral regeneration, though more frequently the disability is confined to the thumb extensors. It is the practice of some surgeons when repairing the musculospiral nerve to transplant the pronator radii teres into the radial extensors, as this procedure will give immediate

extension of the wrist without sacrificing the function of any muscle or interfering with the natural progress of regeneration. We shall therefore consider individually the transplant necessary for the correction of each of these various conditions, though one or all may be corrected during the course of a single operation.

For Restoration of Carpal Extension

a. Pronator radii teres into the extensors carpi radialis longior and brevior to give dorsal flexion of the wrist.

b. Divided extensor carpi ulnaris tendon into the flexor carpi ulnaris prevent radial deviation of the hand.

Technique.

1. The incision extends along the radial border of the forearm in its middle third. The line of cleavage is found between the brachioradialis and the carpal extensors and deepened to expose the radius, where the ribbon-like tendon of the pronator teres is found partially encircling this bone; this tendon is mobilized and divided at its insertion. The tendons of the extensors carpi radialis longior and brevior are now identified, and with the wrist held in hyperextension, the pronator tendon is passed through a slit in these tendons and anchored after proper tension has been attained.

2. To prevent radial deviation of the wrist during extension through pronator teres action on the radiocarpal extensors, the ulnar carpal extensor tendon may be divided and transplanted into the flexor carpi ulnaris. Occasionally also in defective musculospiral regeneration, the extensor carpi ulnaris fails to regain power, and extension of the wrist is associated with marked radial deviation. This transplant is usually very satisfactory for the correction of this condition. Frequently the tendon of the flexor carpi ulnaris is used as a transplant to produce extension of the third, fourth, and fifth fingers, and occasionally also the index; in which case the fleshy part of the flexor carpi ulnaris tendon, which is attached to the ulnar border of this tendon, is detached and separately transplanted into the extensor carpi ulnaris tendon, or the extensor carpi ulnaris tendon may be divided some distance above its insertion and transplanted into the detached fleshy fibers of the flexor carpi ulnaris.

For Restoration of Extension of the Digits

a. Flexor carpi radialis into the extensor ossis metacarpi pollicis, extensor pollicis brevis, and extensor pollicis longus, and occasionally into the extensors indices and communis tendons of the index finger.

b. Palmaris longus into the tendon of the long extensor of the thumb, when the palmaris is present (about 20 per cent of cases) and when the flexor carpi radialis is not used for terminal flexion of the thumb.

c. Flexor carpi ulnaris into the extensor tendons of the little, ring, and middle fingers, and also the index finger when its tendon is not anastomosed to the flexor carpi radialis.

Inasmuch as isolated extension of the index finger is important, with extension of the thumb, in picking up objects, the writer prefers to use the flexor carpi radialis for both thumb and index extension. Some of our most

satisfactory results in extension of the distal phalanx of the thumb have attended flexor carpi radialis transplantation into the long extensor in common with the other extensors of the thumb, though a separate transplantation of the palmaris longus into this tendon is a very satisfactory procedure.

TECHNIQUE.

a. Through a long incision, extending from the insertion of the flexor carpi radialis tendon to the middle of the forearm on its radio-ventral aspect, the tendon of the flexor carpi radialis is exposed, divided at its insertion and freely mobilized to the upper part of the incision, care being taken to avoid injury to the radial artery and nerve lying along its radial border.

b. A second ventral incision of the same length is made along the ulnar border of the forearm, exposing the ulnar tendon, which is divided at its attachment and freely mobilized. The tendon of the flexor carpi ulnaris is split close to its ulnar border, to which muscle fibers are attached almost to its insertion. The splitting of the ulnar flexor tendon in this manner preserves the insertion of its fleshy fibers to which portion the divided extensor carpi ulnaris tendon may be anastomosed. This separation of the flexor carpi ulnaris tendon is extended to the middle third of the forearm, where it is lost in the fleshy portion of its belly. The radial border of the muscle should, however, be mobilized some distance higher, care being taken to avoid injury to the ulnar vessels and nerve which lie below.

c. A mid-dorsal incision is now carried from the wrist joint to the middle third of the forearm, and the fat of the superficial fascia medially and laterally undermined around both radial and ulnar borders of the forearm, connecting subcutaneously, on the radial side, with the radioventral incision, and, on the ulnar border, with the ventroulnar incision. The direction of each tunnel should be arranged in a manner permitting a straight pull from the upper ventral surface of the forearm to the dorsal surface of the wrist, by the transposed extensor tendons. The mobilized flexor carpi ulnaris tendon is now passed through the tunnel to the dorsal aspect of the wrist and passed through a slit in both extensor tendons of the little finger and the common extensor tendons of the ring and middle fingers, while the fingers and wrist are held in complete extension, which extension must be maintained throughout the operation and during subsequent treatment. The undermining of the superficial fascia along the radial border of the wrist will expose the tendons of the extensor ossis metacarpi pollicis and the short extensor of the thumb. Through the dorsal incision the long extensor of the thumb and both extensors of the index finger are identified. The tendon of the flexor carpi radialis is passed through a slit in these tendons, while the thumb is in complete extension and abduction, and the index finger fully extended. When the proper tension has been obtained, the transplant is fixed to each tendon by linen sutures. When it is desired to use the palmaris longus for terminal extension of the thumb, the writer prefers mobilizing and dividing the long extensor of the thumb some distance above the wrist and transposing it to the ventral surface of the wrist for anastomosis into the divided tendon of the palmaris longus; each tendon should be sufficiently mobilized to permit a pull as nearly direct as possible from origin to insertion.

After thorough hemostasis is effected, all incisions are closed, the ventral prior to the dorsal, after which the wrist, thumb, and fingers are maintained in extension by a previously made long "cock-up" splint; care should be used in preventing any hyperextension of the metacarpophalangeal joints. It is often desirable to permit slight flexion of these joints, which greatly adds to the comfort of the patient. (Subsequent treatment and reeducation follow the usual rules for tendon transplantation.)

To Supply Extensor Action to the Thumb

a. Flexor carpi radialis into the extensor ossis metacarpi pollicis, extensor brevis pollicis, and extensor longus pollicis.

b. Palmaris longus into the extensor longus pollicis, when extension of the distal phalanx of the thumb alone is absent, or when it is deemed advisable to use a separate tendon for extending the distal phalanx. The palmaris longus tendon does not appear to be a suitable transplant to use for all the extensors of the thumb.

Technique.

The procedure for transplanting the flexor carpi radialis into the extensors of the thumb or supplementing this with the palmaris longus to the long extensor of the thumb varies in no way from the method described above, except that the mid-dorsal incision may now be shortened and made nearer the radial border of the wrist.

MEDIAN NERVE

GENERAL ANATOMY

The median nerve is formed in the axilla by a union of the anterior divisions of the outer and inner cords of the brachial plexus. The outer cord formed by the fifth, sixth, and seventh cervical nerves contributes the outer head of the median, while the inner cord formed by the eighth cervical and first dorsal supplies the inner head of the median; the union of the two heads takes place usually just below the tendon of the pectoralis minor muscle. The median nerve then passes down the medial side of the arm in the neurovascular bundle in close relation to the axillary and brachial artery. In the axilla the artery will usually be found lying between the forked head of the nerve, being crossed by the inner head before the median trunk is formed. In the lower part of the axilla and upper part of the arm the artery lies immediately behind the nerve. As it progresses down the arm the artery first lies medial to the nerve, but toward the middle of the arm the relation is reversed, the artery crossing to the lateral side. In the upper part of the arm the median nerve is overlapped by the coracobrachialis muscle and the medial border of the biceps. In the lower half of the arm the nerve lies upon the brachialis anticus, becoming superficial as it assumes a more anterior position entering the antecubital fossa. In the antecubital fossa the nerve passes under the bicipital fascia and begins its course down the forearm; passing beneath the superficial or humeral head of the pronator radii teres, it enters its deep position in the forearm by passing under the tendinous arch of the flexor sublimis

digitorum. Crossing the ulnar artery it follows the under surface of the sublimis digitorum, lying upon the flexor profundus. As it approaches the wrist the nerve again becomes superficial, lying in this region under the tendon of the palmaris longus medial to the flexor carpi radialis and lateral to the sublimis tendons. It passes below the anterior annular ligament; and in the palm, lying under the palmar fascia, it remains lateral to the sublimis tendons, where it divides into its terminal digital branches.

BRANCHES

The only branch given off by the median nerve in the arm is in the lower portion of the lower third, where a small branch supplies the elbow joint, though, occasionally, the branches to the pronator radii teres arise in this region. There are, however, many instances in which the median in the arm communicates in various degrees with the musculocutaneous. (See musculocutaneous nerve, p. 993.)

As the median nerve enters the antecubital fossa it gives off branches, usually three in number, to the pronator radii teres. Occasionally the three branches may leave the main median trunk in a single sheath, dividing after leaving the parent nerve. The next branches given off are to the palmaris longus, flexor carpi radialis, and flexor sublimis digitorum, in the order named. Occasionally, however, at this point a single large motor branch is given off from the median, supplying all the median innervated extrinsic muscles. In such cases the branches to the palmaris longus, flexor carpi radialis, and flexor sublimis digitorum first leave this motor portion. The remainder of this trunk, carrying branches to the deep muscles, is commonly known as the anterior or volar interosseous nerve and is accompanied in its course down the arm by the anterior interosseous artery. This branch occupies a position somewhat deeper than the main trunk of the median nerve, lying in the cleft between the flexor profundus digitorum and the flexor longus pollicis, giving branches to these muscles in its earlier course and terminating in the wrist by supplying the pronator quadratus muscle and sending filaments to the radioulnar articulation and the wrist joint. The motor branches to the extrinsic muscles, however, may leave the parent trunk with many variations, superficially arising from both sides of the median trunk. When, however, these branches are followed a short distance up the parent trunk it will be found that they arise from those funiculi which occupy the medial half of the nerve, the most ventral fibers supplying the pronator radii teres. Medial and slightly posterior to the pronator funiculi lie the fibers to the palmaris longus, flexor carpi radialis, and flexor sublimis digitorum, while the funiculi to the flexor profundus digitorum and flexor longus pollicis encroach upon the posterior surface of the nerve. All these motor branches, however, are located on the medial side of the nerve and may be followed up the nerve trunk by an intraneural dissection for some distance, occasionally as high as the middle of the arm. Often the branches supplying the deep muscles (volar interosseous nerve) leave the median trunk as an individual lower branch. Just above the wrist the median nerve gives off a sensory palmar cutaneous branch, which passes above the annular liga-

ment. After passing into the palm the median gives off motor branches from its radial side to supply the opponens, abductor, and superficial head of the flexor brevis pollicis. In the region of the superficial palmar arch the nerve becomes enlarged and flattened, dividing into two branches, which in turn subdivide into five terminal cutaneous sensory branches. These branches, shortly after their origin and occasionally before, give off motor branches to the first and second lumbricales muscles.

SURGERY

IN THE ARM

Axillary portion.—Lesions involving the median nerve in the axilla are seldom isolated lesions; they are usually combined with injuries to contiguous elements in the neurovascular bundle, so that from a surgical standpoint lesions of the median nerve in the axilla are treated as lower plexus lesions. (See lower plexus lesions, p. 984.)

In the arm.—Lesions of the median nerve in the arm are seldom confined to this nerve. The close proximity of the ulnar trunk, the brachial artery, the basilic vein, and the internal cutaneous nerve makes combined lesions more frequent in the upper two-thirds of the arm, while in the lower third the ulnar and internal cutaneous are frequently spared.

Exposure of the median nerve in the arm is best accomplished with the arm in abduction and outward rotation. The incision follows the medial border of the coracobrachialis above and the biceps below. These structures somewhat overlap the nerve along its humeral course. In the upper part of the arm the nerve will be found lying lateral and anterior to the artery; below the mid portion it crosses the artery and lies on the medial side. The vein and artery are so commonly involved in median injuries in this location that special care should be used in dealing with these structures to prevent undue bleeding, particularly if the lesion is associated with much scar tissue. It is always essential that these vascular structures be isolated above and below the field of scar tissue invasion. With the control of these vascular channels, the surgeon is usually master of the situation and the dissection is greatly facilitated.

In the arm the median nerve gives off no important branches; however, often it communicates by various types of anomalies with the musculocutaneous, explaining certain median lesions in which, at operation, the nerve is found to be completely divided, though the clinical examination reveals incomplete median anesthesia, or the retention of motor power in the median muscles. In making a diagnosis of partial median injury, anomalous communications between the median and musculocutaneous nerves should always be borne in mind. Electrical stimulation of the median nerve in suspected partial lesions will produce contraction in the unparalyzed median muscles, if it be a true partial lesion. If this stimulation fails to elicit contraction in these muscles, stimulation of the musculocutaneous, which is easily accomplished by identifying its trunk on the dorsal surface of the biceps, will indicate the nature of the innervation, if it be due to a median and musculocutaneous anomaly. Retained

function, motor or sensory, when the median trunk shows complete anatomical division, is usually due to median fibers passing down the musculocutaneous trunk and joining the median below the lesion. This refers entirely to the extrinsic muscles; the intrinsic hand muscles, particularly the superficial head of the flexor brevis pollicis may not be paralyzed in complete median paralysis, in which case it is probably wholly innervated by ulnar branches.

When median lesions in the arm are associated with irritative or marked vasomotor phenomena, particular attention should be given to complete isolation and decortication of the brachial artery (peri-arterial sympathectomy, after the method of Leriche). In the writer's experience this has occasionally relieved painful nerve syndromes where all other methods have failed. In median causalgia or severe median irritative lesions without anatomic division of the nerve an internal neurolysis is also indicated if the median trunk presents any evidence of scar induration upon palpation.

The prevention of torsion of the median trunk in the arm is best accomplished by the use of accurately placed identification sutures before the nerve has been completely isolated from its bed. The anatomic method of fascicular identification, by relying upon motor branches, can be utilized only in low lesions in the region of the internal condyle, where a branch is given off to the pronator teres. This branch, however, may be followed some distance up the median trunk as a well identified funiculus. Its intraneural localization will reveal the anterior and medial portion of the nerve trunk in this region, it being the most anterior of the motor bundles. The determination of funicular topography above the branches to the pronator radii teres is possible only by the electro-anatomic method, which will serve, if properly conducted, to identify the position of the sensory bundles, which lie in the lateral aspect of the median trunk. When secondary sutures are indicated, because of torsion during the original suture, identification sutures are of no value and resuturing must be guided by localization obtained by the electro-anatomic method of identification.

IN THE ANTECUBITAL FOSSA AND UPPER TWO-THIRDS OF THE FOREARM

The position of the arm for exposure of the median nerve in this region is one of abduction and external rotation, with the forearm in complete supination.

The median nerve, after entering the antecubital fossa at the bend of the elbow assumes a very deep position through the upper two-thirds of the forearm, though it becomes more superficial as it approaches the wrist. Exposure of the nerve in the forearm is greatly facilitated by a clear understanding of certain anatomic relationships. The operator attempting this exposure should avail himself of an opportunity to become familiar with these points, by recourse to the dissecting room, if his visualization of this regional anatomy is at all obscured. The following anatomic points require special consideration: (1) The anatomy of the antecubital fossa; (2) the relation of the pronator radii teres to the median nerve; its insertion in the radius and its relation to the flexor carpi radialis; (3) the radial origin of the flexor sublimis digitorum and the arching fibers of this origin, which surround the nerve; (4) the relation of the median nerve in the wrist to the tendons of the palmaris longus and flexor carpi radialis.

The antecubital fossa is a triangular space, the base above being formed by an imaginary line connecting the humeral condyles. The medial boundary is formed by the lateral edge of the pronator radii teres, while the lateral border is formed by the medial edge of the brachioradialis. The biceps tendon passes through the lateral side of the fossa. Both nerve and artery rest upon the floor of the fossa which is formed by the brachialis anticus. In the lower part of the fossa, the brachial artery divides into its radial and ulnar portions. The fossa is covered by the deep fascia and in its lower part by that thickened portion of the deep fascia which constitutes the bicipital fascia. Exposure of the nerve in or just above the antecubital fossa is facilitated by identifying the medial border of the biceps and its tendon; both the nerve and artery lie to its medial side. A tape placed around the artery in the upper part of the incision will facilitate its control in case of emergency, while making a scar tissue dissection, the vein being controlled from below.

Fig. 176.—Exposure of median nerve in lower arm and upper forearm, showing its relation to the brachial artery and biceps; both artery and nerve are covered by the bicipital fascia. A, Median nerve; B, brachial artery; C, branch to pronator teres; D, radial artery; E, bicipital fascia; F, internal intermuscular septum; G, ulnar nerve; H, medial epicondyle; I, deep fascia covering superficial flexors

The pronator radii teres passes from the internal humeral condyle diagonally across the forearm to be inserted in the middle of the radius by a long flat tendon which partially encircles the bone. This muscle forms the lower medial boundary of the antecubital fossa. It is composed of two heads, a large superficial head taking origin from the internal condyle in common with the other superficial mucles. The deep head of the pronator arises from the ulna and is very much smaller than the superficial head. The median nerve passes in the cleft between the two heads of the pronator. The radial artery, after the division of the brachial, passes to the radial side of the forearm above the pronator teres, while the ulnar artery directed to the ulnar side, passes beneath the deep head of the pronator and is thus separated from the median nerve. The lower or medial border of the pronator has a direct fascial attachment with its adjoining muscle, the flexor carpi radialis. The insertion of the pronator into the radius is covered by the brachioradialis, and along the under surface of the latter passes the radial nerve. The median nerve in the antecubital fossa

and under the superficial head of the pronator gives off its important motor branches to the extrinsic muscles. In this region great care must be used for the preservation of these branches. Their exit from the parent trunk may be, superficially, from either side. Their deep origin within the median trunk is from the medial portion of the nerve; the lateral being the sensory portion. The branches to the pronator, the flexor carpi radialis, and

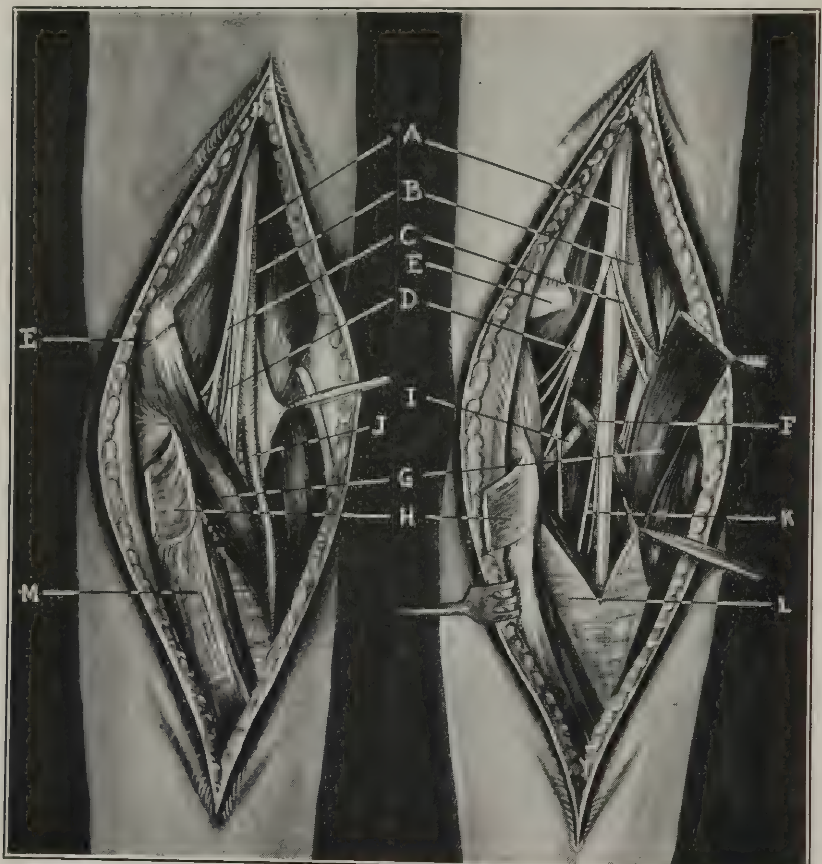

FIG. 177.—A, Exposure of median nerve in the antecubital fossa; bicipital fascia divided, pronator teres mobilized from its attachment to flexor carpi radialis. B, Humeral head of pronator teres divided and retracted, exposing branches of the median nerve in this region. Deep head of pronator is seen passing below the median nerve and crossing the ulnar artery. Branches of the median nerve to the forearm muscles are shown springing from its medial side. A, Median nerve; B, brachial artery; C, branches to pronator teres; D, motor branches to superficial flexors; E, medial epicondyle; F, pronator teres, deep head; G, pronator teres, superficial head; H, bicipital fascia; I, ulnar artery; J, radial artery; K, motor branches to deep flexors; L, flexor sublimis digitorum, split; M, flexor carpi radialis

the palmaris longus are usually given off higher than the branches to the deep muscles.

Exposure of the nerve under the pronator is best accomplished by dividing its tendon near its insertion into the radius, care being taken to avoid the radial nerve and artery which pass over the tendon in this region. The radial artery must be mobilized and freed from this muscle, which will necessitate the liga-

tion of several small branches. After the tendon of the pronator has been divided, this muscle may be reflected toward the medial side of the forearm, exposing its under surface and deep head which will be found passing around the median nerve. After the division of the pronator tendon, its medially adjacent muscle, the flexor carpi radialis, may be partially retracted toward the medial side of the forearm, exposing the flexor sublimis digitorum and *its tendinous arch*, which in reality is the keynote of the situation.

The flexor sublimis digitorum.—The points to be remembered in connection with this muscle are that it covers the median nerve, which passes along its posterior surface; it arises from four heads, the first three of which are from the ulna side and more or less in common with the superficial muscles; the fourth head is from the radius, and the fibers radiating between the radial and humeral heads form an arch under which the median nerve and ulnar artery pass. The radial head should be carefully divided and the muscle gently retracted toward the medial side of the forearm with the pronator. This procedure will give adequate exposure of the median nerve throughout its deep portion.

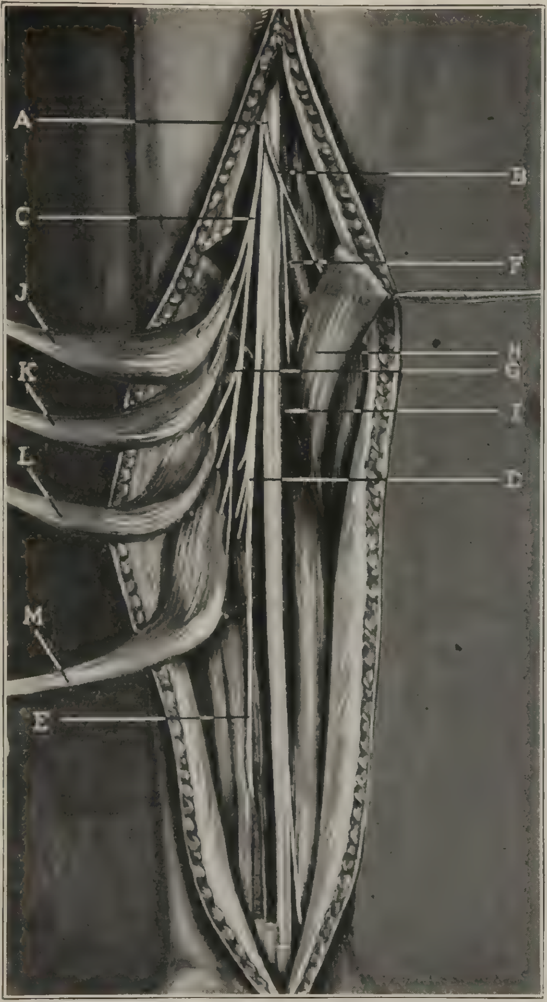

FIG. 178.—Intraneural dissection of median branches in the forearm, showing their origin from the medial or motor side of the median trunk. Highest branches to be given off are to the pronator, whose branches originate from the most ventral portion of the motor quadrant. The volar interosseous likewise arises from the medial side of the median trunk, though occupying a more dorsal position than the bundles to the superficial muscles. A, Median nerve; B, branch to pronator teres; C, branches to superficial flexors; D, branch to deep flexors; E, branch to pronator quadratus; F, division of brachial artery; G, ulnar artery; H, pronator teres, superficial head; I, pronator teres, deep head; J, flexor carpi radialis; K, palmaris longus; L, portion of flexor sublimis digitorum; M, flexor carpi ulnaris

The median nerve above the wrist occupies a relatively superficial position, lying beneath and to the radial or lateral side of the palmaris longus tendon; in the absence of this tendon, the nerve will be found just internal to the tendon of the flexor carpi radialis. If the forearm has suffered extensive scar invasion, with destruction of tendons, etc., it may be necessary to first locate the nerve in this position at the wrist.

Exposure in the Forearm

Exposure of the median nerve in the forearm is accomplished by a straight incision of the desired length, extending from the medial side of the biceps just above the antecubital fossa, in a line toward the insertion of the flexor carpi radialis tendon. In most instances, it is necessary to extend the incision from the upper part of the antecubital fossa to the lower third of the forearm. In the upper part of this incision the median basilic vein is exposed and divided between forceps. At a point corresponding to the insertion of the biceps tendon, the sensory portion of the musculocutaneous nerve is usually encountered in the superficial fascia and its fibers preserved if possible. In the upper part of the incision the contents of the antecubital fossa are exposed by dividing the deep and bicipital fascia: the median nerve and the brachial artery are now identified as they pass along the medial side of the biceps tendon, the artery lying between the nerve and the tendon. The median nerve may now be followed to where it passes below the superficial head of the pronator. In the antecubital fossa, great care should be exercised in avoiding injury to the motor branches to the pronator and the extrinsic muscles. If this exposure is not sufficient to identify the lower segment of the nerve, it must be approached in the lower third of the forearm and followed upward. To permit a lower exposure, the skin incision is extended to the lower third of the arm and the deep fascia divided, exposing the tendon of the flexor carpi radialis, and the median nerve located below the tendon. At the junction of the middle and lower third of the forearm, the median nerve is somewhat deeper than at the wrist, and it may be exposed by retracting the tendon of the flexor carpi radialis laterally, exposing below the aponeurotic medial edge of the flexor longus pollicis; the nerve will now be found in the cleft between the latter muscle and the flexor sublimis digitorum. The median nerve, having been exposed in the upper and lower thirds of the forearm, will require exposure in its middle third, where it is deeply placed between the sublimis and profundus digitorum muscles. Exposure of the median nerve in the middle third of the forearm is the most difficult step in the operation, and is accomplished by dividing the tendon of insertion of the pronator radii teres and reflecting this muscle with the flexor carpi radialis medially, exposing the radial head of the flexor sublimis digitorum, which in turn is divided and also retracted medially; the nerve is identified as it lies on the ventral surface of the profundus digitorum. If precaution is not taken, serious trouble may be experienced in this exposure through injury to arterial twigs leaving the radial artery. The brachial artery, before it divides into its terminal radial and ulnar divisions in the antecubital fossa, may be secured for control by the passage of tape around the vessel, which may be tightened at will. The radial artery passes over the tendon of the pronator radii teres near its insertion in the radius and passes down the forearm under cover of the brachioradialis, accompanied by the radial nerve. In its course down the forearm, the radial artery gives off numerous twigs which must be ligated before attempting division and retraction of the pronator. After the radial artery has been mobilized, it is retracted medially with the brachioradialis, exposing the flattened tendon of the pronator, which is divided, and the muscle belly reflected. The radial or lateral edge of the flexor carpi radialis is freed

and retracted with the pronator, exposing the ventral surface of the flexor sublimis digitorum. With the reflection and exposure of the under surface of the pronator, the median nerve will be found passing between its two heads, the deep head of this muscle being but little larger than the median trunk—it may be divided to permit mobilization of the nerve. The median nerve may now be followed to where it disappears below the arched fibers connecting the two heads of the flexor sublimis digitorum. The radial head of this muscle is small and fibrous, and should be divided to permit its medial reflection, which is readily accomplished after freeing its radial border: the median nerve is now completely exposed throughout the forearm. Its important motor branches are given off in the lower part of the antecubital fossa, in the middle third of the forearm beneath the pronator and the early part of its course below the sublimis. In making this exposure, great care should be used in preventing injury to these branches. The identification of branches should proceed from above downward, resorting to electrical stimulation to confirm identification, if branches are intact. (See general anatomy of the median nerve, p. 1013.)

Fig. 179.—Median nerve lesion in middle third of forearm; nerve exposed above and below lesion and marked with identification sutures. In this instance the nerve is exposed below the pronator teres by dividing the flexor sublimis digitorum. A, Branch to pronator teres; B, pronator teres; C, bicipital fascia; D, flexor carpi radialis; E, median nerve, upper segment; F, flexor sublimis digitorum, split; G, median nerve, lower segment; H, median nerve; I, brachial artery; J, radial artery; K, brachioradialis

Physiologic Approximation in the Upper Two-Thirds of the Forearm

Before complete dissection of the nerve is attempted, the center of its ventral quadrant should be marked with identification sutures to be used in subsequent alignment during approximation. In approximation of the median nerve in the upper forearm, it is essential that the branches to the pronator and long flexor muscles be identified and preserved during dissection, and if they have suffered individual division, they should be separately sutured. Inasmuch as most of the branches to the extrinsic muscles are given off in the region of the pronator teres, lesions above this point will probably involve most of these branches before they have left the median trunk. It is essential, therefore, that the medial side of the nerve trunk be accurately identified in both proximal and distal ends of the divided nerve, as the bundles forming the motor branches are located in this portion of the median trunk, the fibers to the pronator being more

ventral than those to the palmaris longus, flexor carpi radialis, and sublimis digitorum. Often in this region a dissection of the median trunk will reveal all its motor branches incorporated in an individual sheath, lying along the medial side of the nerve. In such instances, individual approximation of the motor segment is possible.

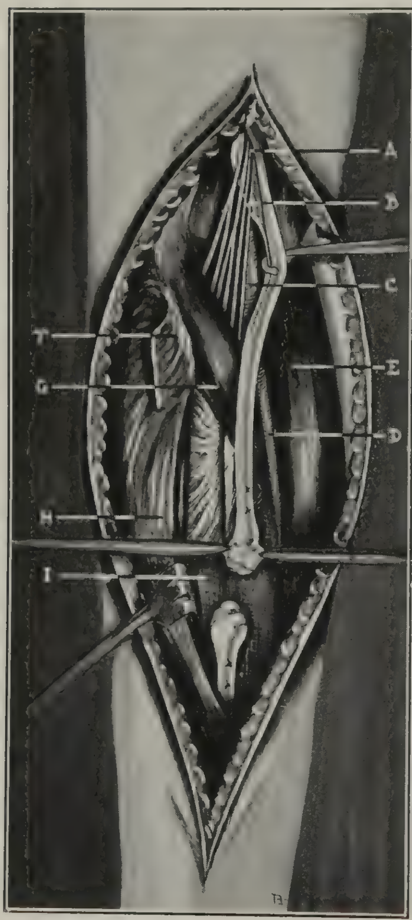

FIG. 180.—Transposition of median nerve to a plane superficial to superficial head of pronator radii teres. Intraneural mobilization of branches. Continuity defect may now be overcome by flexion-relaxation of elbow. A, Median nerve; B, motor branches, mobilized; C, brachial artery; D, radial artery; E, brachioradialis; F, bicipital fascia; G, pronator teres; H, flexor carpi radialis; I, flexor sublimis digitorum

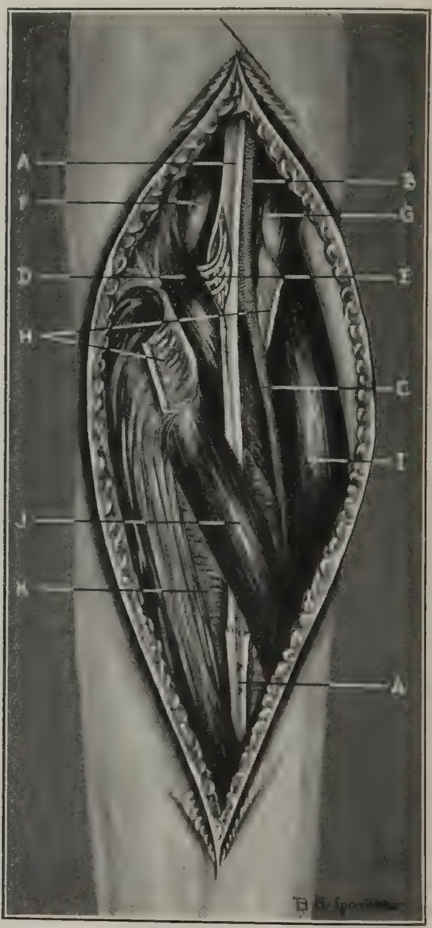

FIG. 181.—Median nerve transposed to overcome median defect and sutured; nerve now passes superficial to pronator radii teres and below flexor carpi radialis. Nerve sheath partly closed. A, Median nerve; B, brachial artery; C, radial artery; D, pronator teres; E, motor branches; F, brachialis anticus; G, biceps; H, bicipital fascia; I, brachioradialis; J, flexor carpi radialis; K, flexor sublimis digitorum

Lesions of the median trunk below the pronator seldom involve all its motor branches, though in extensive lesions many of them may suffer individual injury. The motor branches to the profundus digitorum, flexor longus pollicis, and pronator quadratus may be given off from the medial side of the nerve below the flexor sublimis digitorum, as individual branches, but more often they

leave the nerve trunk as the volar interosseous nerve in the region of the pronator, and occasionally it is possible to effect individual suture of this rather large branch, which will be found passing down the cleft between the profundus digitorum and the flexor longus pollicis, accompanied by the volar interosseous artery.

After the motor branches to the extrinsic muscles have left the median trunk, its content in motor fibers consists solely of those to the median intrinsic hand muscles, which lie in the dorsal quadrant of the nerve. Though the intrinsic hand muscles seldom recover function after a long period of denervation, the operator should exert just as great care in preventing torsion of the median trunk in this region, for a disturbance of its sensory pattern will result in defective tactile localization, which will greatly diminish the functional usefulness of the digits.

CONTINUITY DEFECTS

If the continuity defect of the nerve be too great to be overcome by primary stretching and flexion-relaxation of the elbow and wrist joints, transposition is indicated, in which the median nerve is transposed to a position above the superficial head of the pronator teres. In order to make this procedure available, the motor branches must be gently mobilized by an intraneural dissection of the nerve trunk after its sheath is opened; failure to do so will result in their destruction. Most of these motor branches may be readily isolated from the parent trunk to some distance above the medial condyle. The median nerve in its transposed position passes along the radial border of the flexor carpi radialis above the pronator teres. A transposition of this nature will usually shorten the distance of a defect from 4 to 7 cm. during forearm flexion. If, after transposition, it still remains impossible to approximate the nerve ends, the unsectioned ends of the nerve should be sutured for secondary stretching and resort made to the two-stage operation, rather than to grafting. Failing in this, the surgeon's only recourse will probably be to grafting, for which the radial nerve, lying just under the exposed brachioradialis may be used to advantage.

MEDIAN LESIONS AT THE WRIST AND COMBINED TENDON INJURIES

Most lesions involving the median nerve at the wrist are combined with lesions of the flexor tendons. It is therefore necessary to exercise great care in these dissections, for the normal anatomic relationships are frequently lost with the destruction of the tendons. It is advisable always to first identify and isolate the median nerve to prevent secondary injury to this structure during the dissection of the tendons.

Exposure at the Wrist

It is essential to identify the tendon of the palmaris longus, if this muscle be present; likewise the tendon of the flexor carpi radialis. The median nerve passes under the annular ligament just below the palmaris longus tendon, to the ulnar side of the flexor carpi radialis tendon and to the radial side of the

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sublimis tendon; identification of these structures will usually facilitate exposure of the nerve. If the lesion is low, it may be necessary to divide the annular ligament and palmar fascia, exposing the nerve in the palm where it may be readily identified as it passes along the radial side of the sublimis tendons.

If difficulty is experienced in locating the upper end of the nerve, the flexor carpi radialis tendon should be followed up, exposing the line of cleavage between the tendon of the flexor sublimis digitorum and the flexor longus pollicis. Retraction of the flexor sublimis digitorum will usually reveal the nerve on the under surface of this muscle. If this exposure fails to reveal the location of the nerve, it may be necessary to locate it as it passes under the pronator radii teres and the tendinous arch of origin between the heads of the flexor sublimis digitorum, as in middle forearm exposures. The palmar cutaneous branch is given off from the anterior surface of the median, a few centimeters above the annular ligament; in the presence of much scar tissue its identification is extremely difficult and when possible its repair should be attempted. After the median nerve has been located and before it has been completely isolated from its bed, it should be carefully marked with identification sutures, as in the lower third of the forearm funicular topography can not be determined by branch identification. Occasionally, advantage may be taken of the fact that the anterior surface of the nerve is frequently marked by the comes nervi mediana artery passing along its sheath; this artery is quite large and its presence may facilitate surface identification. Electro-anatomic identification at the wrist is of but little value, as the greater bulk of the nerve in this region consists of sensory fibers, its only motor fibers being those to certain intrinsic hand muscles which are located in the dorsal part of the nerve trunk. Even though the nerve is mostly sensory in this region, it is necessary to prevent torsion during suture, for sensory fibers normally innervating one finger may be directed to another, resulting in confusion of tactile localization. The writer has observed an officer whose median nerve was sutured at the wrist; after four years there was a complete return of all forms of sensation, though touch on the third finger was always localized in the thumb, which inhibited to a considerable extent manipulative dexterity in handling small objects. This officer is gradually becoming accustomed to this sensory perversion, by psychological reversion and experience. This case serves to illustrate the confusion arising from the distortion of sensory fibers during suture.

Repair of Tendons in Combined Nerve and Tendon Lesions

After the nerve has been properly identified and isolated, and before suture or the resection of scar tissue from its ends, the injured tendons must receive careful attention. They should be completely isolated from the scar tissue and every vestige of scar carefully removed with as little trauma as possible. Tendons completely divided should be resutured and when this is impossible, because of extensive destruction, they should be united to neighboring tendons having like function. The surgeon should always endeavor, in reconstructive surgery of the wrist, where distortion of the original tendon

pattern is necessary, to provide tendon anastomoses of a physiologic type for both ends of each divided tendon. After the tendons have been properly cared for and perfect hemostasis assured, the ends of the divided nerve may be prepared and approximated, with due respect to physiologic alignment. Flexion of the wrist will assist in facilitating approximation, though when this is necessary in the presence of combined tendon lesions, flexion of the fingers is not advisable. Early gentle passive movements are essential to success in combined nerve and tendon lesions of the wrist, and these passive movements should be persistently encouraged throughout the healing process, until such a time as they may be replaced by active movements, endeavoring always to simulate the full range of normal coordinated hand and finger movements; the importance of these passive exercises can not be too strongly emphasized; they should be begun not later than 48 hours after the operation.

Surgery of the Median Nerve in the Hand

Only occasionally is it possible to effect suture of the terminal digital branches of the median nerve. In the presence of extensive scar tissue it will probably be found impossible, though small incised lesions may lend themselves to successful repair. The writer has on two occasions been successful in effecting satisfactory suture of the median nerve in the palm where the injury was caused by a penetrating gunshot wound. In one instance, the suture was effected just before the nerve divided into its terminal digital branches. In the other instance, the division was about the point where the terminal branches were given off. In this case the individual branches were collected and united to the end of the trunk, apparently without torsion, as regeneration resulted in accurate tactile localization,

Occasionally the median nerve in the hand may be incorporated in scar tissue, producing an irritative syndrome, with retained sensation. Neurolysis will usually give relief. Incised wounds of the fingers occasionally present sensitive neuromas, which are a source of constant annoyance. In such instances the nerve should be exposed and sutured if possible; when approximation fails, the neuroma should be excised, the end of the branch strongly ligated and, proximal to the ligature, injected with pure alcohol.

Exposure in the Palm

Exposure of the median nerve in the palm is accomplished by an incision extending from the insertion of the palmaris longus tendon into the palmar fascia to a point corresponding to the interval between the index and ring fingers. The incision is carried through the integument and fat of the superficial fascia, exposing the palmar fascia, which is divided in the line of the cutaneous incision. The long flexor tendons are identified, and at the base of the palm the median nerve will be found lying to the radial side of these tendons. Shortly after the nerve passes under the annular ligament branches are given off, which pass radially to innervate the superficial thenar muscles, and supply sensation to the thumb. It is highly essential that these branches be preserved as they control to a great extent the opposing function of the thumb.

As the median nerve progresses through the palm it attains a position superficial to the flexor tendons, but passes below the superficial palmar arch. Proximal to the metacarpophalangeal joints the nerve divides into its terminal branches, where it is enlarged, flattened, and, in contrast to the fatty tissue in which it lies, has a somewhat pinkish color. The median divides into five terminal branches, supplying sensation to the first three and radial half of the fourth fingers. These branches may readily be identified, as they lie imbedded in the deep palmar fat, superficial to the flexor tendons, providing the operator has achieved adequate hemostasis, which is highly essential in such dissections and which in the writer's experience has been satisfactorily accomplished only by the use of infiltration anesthesia, containing a small amount of active adrenalin to blanch the tissues.

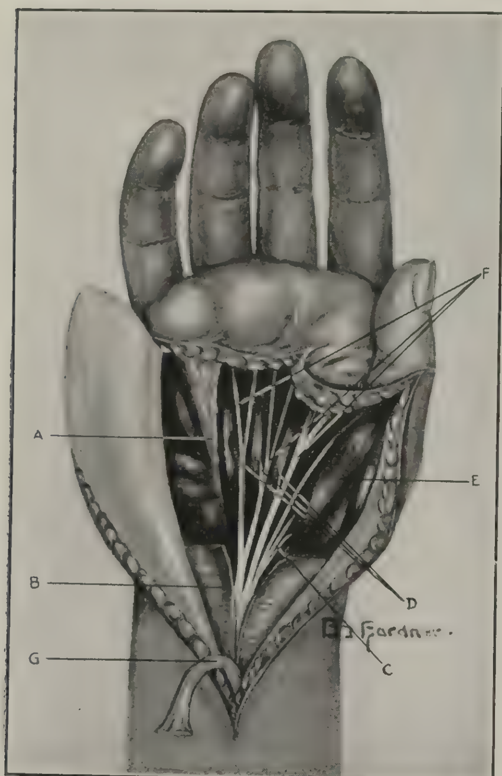

FIG. 182.—Branches of median nerve in hand. A, Palmar fascia, cut edge; B, annular ligament; C, median branches to thenar muscles; D, branches to lumbricales; E, thenar muscles; F, digital sensory branches; G, palmaris longus tendon

IRREPARABLE LESIONS

Irreparable median nerve lesions present a serious problem. Though the action of extrinsic muscles be retained and finger and thumb movements fairly well preserved, the loss of sensation in the first three fingers is a serious handicap and every endeavor should be made to restore, if possible, some type of sensation in the median distribution to the fingers. The surgeon may have recourse to autogenous grafts and may utilize a segment removed from the radial nerve. If this seems impractical, because of extensive scar tissue formation, the procedure of uniting the radial to the median, recommended and practiced by Harris, may be considered. In this procedure, the distal end of the radial nerve is divided at a point where it may be brought in contact with the lower segment of the median, to which it is anastomosed, for the purpose of supplying the anesthetic digits with a radial sensory innervation. It must be remembered, however, that this sensation is localized in the normal radial sensory area. It may correct trophic disturbance and serve in the prevention of injuries to the digits, but the function of tactile localization, so necessary to manual dexterity, is lacking.

In median lesions with extensive continuity defects, the severity of the lesion to the surrounding parts makes the possibility of successful grafting rather remote; the functional disability remaining after radial anastomosis renders this operation a procedure of last resort. It behooves the surgeon, therefore, to exert every effort to procure end-to-end suture of the median, using the two-stage operation, and if necessary, extending the dissection high up in the arm, or even in the axilla. If there also exists a combined ulnar lesion with paralysis of the ulnar intrinsic hand muscles, which has existed beyond one year, and the proximal end of the ulnar is in a position where it may be brought in contact with the distal end of the median, the ulnar may be anastomosed into the median. This procedure will give, perhaps, better functional results than radial anastomosis, though it precludes the possibility of subsequent ulnar regeneration with a continuation of complete anesthesia in the little finger, and interossei paralysis. After one year, it is extremely doubtful whether interossei regeneration would ever occur, and the little finger, if necessary, may be amputated, if trophic changes and traumatic insults to his anesthetic member should necessitate such a procedure.

TENDON TRANSPLANTATION FOR PARALYSIS OF THE MEDIAN NERVE

If it is possible to provide sensation to the fingers and hand, a varying degree of functional usefulness may be restored, even though there exists a complete paralysis of all median innervated muscles. The flexor profundus digitorum, supplied by the ulnar, provides flexion of the fourth and fifth fingers, and frequently the middle finger. The problem, therefore, consists in restoring flexion and opposition to the thumb, and flexion to the index finger and occasionally the middle. Frequently the ulnar supplies the superficial head of the short flexor of the thumb, or a slight change in the insertion of this muscle diminishes greatly the disability of opponens paralysis, so that in a certain number of cases opposing thumb function is fairly well preserved and tendon transplantation is required only to restore function in the long flexors of the thumb and index finger.

In those cases of median paralysis in which the thumb is displaced laterally and can not be made to assume its normal opposed position, an arthrodesis of the carpometacarpal joint in a position of opposition and abduction with an angle of about 60° between the first and second metacarpals, as recommended by Baldwin, is a very satisfactory procedure. A fibrous ankylosis probably gives better results after this arthrodesis than a solid bony ankylosis. Ney has obtained very satisfactory opponens function of the thumb by tendon transplantation, in which the short extensor of the thumb is divided at the wrist and freed to its insertion. The palmaris longus is then exposed and divided just above the annular ligament. The short extensor of the thumb is now passed through a tunnel under the subcutaneous fat of the thenar eminence to the palm of the hand, and after being passed under the annular ligament is transplanted into the tendon of the palmaris longus, or, the latter muscle being absent, into the flexor carpi radialis. If the flexor carpi radialis and palmaris longus are paralyzed, it may be inserted into the extensor

carpi radialis tendon or the flexor carpi ulnaris tendon, which are being utilized to restore flexion to the distal phalanx of the thumb and the index finger. This procedure for obtaining opponens action finds its greatest usefulness in combined median and ulnar lesions with complete intrinsic hand muscle paralysis, under which subject the technique is described in detail.

For Paralysis of the Long Flexor of the Thumb and the Flexors of the Index Finger

An incision is made about 5 cm. long from the base of the metacarpocarpal joint of the thumb along the radial border of the forearm, following the radial edge of the flexor carpi radialis. Undermining this incision medially, the deep flexor tendons are exposed and the long flexor of the thumb located just below the tendon of the flexor carpi radialis. Retraction of the edges of the wound laterally will expose the tendon of the extensor ossis metacarpi pollicis which is divided near its insertion into the base of the first metacarpal bone. The radial artery and its several branches lie in the space between these tendons and may require ligation. After the tendon of the extensor ossis metacarpi pollicis has been freed and divided it is anastomosed to the divided end of the flexor longus pollicis, under sufficient tension to insure flexion of the distal phalanx of the thumb. The flexor tendons to the index finger may now be identified and freed. An incision on the dorsum of the wrist over the tendon of the extensor carpi radialis is made from its insertion some distance up the forearm. The tendon of the radial carpal extensor is divided, carefully mobilized, and passed through a subcutaneous tunnel from the dorsum of the forearm to the incision on the ventral surface and transplanted into both flexor tendons of the index finger. During this procedure the wrist is held in flexion and the index finger about half flexed. It is essential in the postoperative treatment that early passive movements be instituted to prevent adhesions, which would tend to keep the index finger in permanent flexion. In our experience these procedures have given perhaps the best results, though very satisfactory results have followed a transplantation of the index flexor tendons into the flexor carpi ulnaris.

ULNAR NERVE

GENERAL ANATOMY

The ulnar nerve arises from the inner cord of the brachial plexus in common with the inner head of the median and the internal and lesser internal cutaneous nerves, most of its fibers being derived from the anterior divisions of the eighth cervical and first thoracic roots. The nerve lies medial to the inner head of the median and lateral to the internal cutaneous. In passing through the axilla and the upper two-thirds of the arm, the ulnar occupies a position medial to the artery and the median nerve in the neurovascular bundle. In the lower part of the middle third of the arm the nerve leaves the neurovascular bundle, and penetrating the internal intermuscular septum follows a posterior course to a position posterior to the internal humeral condyle, lying in close relation to the posterior surface of the internal intermuscular septum, and crossing the fibers of the medial head of the triceps, which

arise from this portion of the septum. In this region the ulnar nerve is accompanied by the inferior profunda artery, which usually lies on its ventral surface. The profunda artery in the region of the internal humeral condyle anastomoses freely, as does its venæ comites, with the posterior ulnar recurrent artery and veins. Behind the medial condyle the ulnar nerve occupies a very superficial position and is covered by a thick, aponeurotic fascia, which extends from the condyle to the olecranon. The nerve enters the forearm by passing under an aponeurotic arch, connecting the humeral and ulnar heads of the flexor carpi ulnaris, and continues its course down the forearm, covered by the belly of this muscle and lying on the profundus digitorum. In the upper third of the forearm the ulnar nerve is separated some distance from the ulnar artery, while in the middle and lower thirds they lie in direct contact. In the middle and lower thirds of the forearm the ulnar nerve lies dorsal to the tendon of the flexor carpi ulnaris; at the wrist it passes through a special compartment in the anterior annular ligament to the radial side of the pisiform bone to enter the palm, where it divides into its terminal superficial and deep palmar branches.

BRANCHES

The only branches of the ulnar nerve given off in the arm are in the region of the internal humeral condyle, where several small twigs are distributed to the elbow joint. About 2 cm. below the medial condyle two branches are given off to the two heads of the flexor carpi ulnaris; at a slightly lower level another set of branches is given off to the ulnar side of the flexor profundus digitorum. These motor branches arise from the medial side of the dorsal quadrant of the nerve; they pursue a relatively long intraneural course and may be followed up the ulnar trunk for some distance above the medial condyle by an intraneural dissection. In the middle third of the forearm the ulnar gives off a relatively insignificant palmar cutaneous branch, which distributes branches to the ulnar artery and follows the artery to the annular ligament, over which it passes to supply a small area at the base of the hypothenar eminence. At the junction of the middle and lower third of the forearm there springs from the medial side of the ulnar trunk a large *dorsal cutaneous branch*, which at times nearly approximates the ulnar trunk in size This dorsal cutaneous branch, after passing under the tendon of the flexor carpi ulnaris to the dorsal aspect of the wrist, becomes cutaneous and supplies sensation to the ulnar dorsal border of the hand, and to the dorsum of the little finger as far as its terminal phalanx and the ring finger to its middle phalanx.

Terminal palmar branches.—After passing under the annular ligament the ulnar nerve terminates in a superficial and deep branch. The *superficial branch*, beyond giving a few twigs to the palmaris brevis muscle, is strictly sensory and supplies sensation to the ulnar side of the palm and divides into an outer and inner digital branch, supplying sensation to the little finger and adjacent side of the ring finger. The *deep branch* is principally motor; after its separation from the ulnar trunk, it gives off branches to the muscles of the little finger and enters its deep course in the palm, accompanied by the ulnar

artery, by passing between the abductor and flexor brevis minimi digiti muscles, penetrating the opponens minimi digiti. It follows the course of the deep palmar arch beneath the flexor tendons, giving off branches to the dorsal and palmar interossei muscles and the two inner lumbricales, and terminates by sending motor branches to the adductor pollicis and the inner head of the flexor brevis pollicis.

SURGERY

Lesions of the ulnar nerve in the axilla are usually combined lesions of the terminal plexus type, and are dealt with as such.

In the upper arm the ulnar nerve lies within the neurovascular bundle, and any traumatism sufficient to injure the ulnar will probably result in injury to the median. As the ulnar nerve leaves the axilla under the lower border of the pectoralis major, it passes across the tendon of the latissimus dorsi, in close relation to the musculospiral, and in this region both occasionally suffer simultaneous injury.

EXPOSURE IN THE ARM

Exposure of the ulnar nerve in the upper part of the arm is obtained as with the median, through a long incision, paralleling the neurovascular bundle. This incision differs, however, in that at the junction of the middle and lower third of the arm it diverges posteriorly, following the internal intermuscular septum to the medial humeral condyle. The deep fascia is now opened and the medial border of the coracobrachialis above and the biceps below retracted, exposing the neurovascular bundle, which lies in the cleft between these muscles and the long head of the triceps. At the lower part of the axilla the neurovascular bundle is covered by the pectoralis major and, to obtain an axillary exposure, the pectoral tendon will require division. The neurovascular bundle is opened, exposing its contents and the ulnar nerve identified above the lesion. About the junction of the middle and lower third of the arm the lower segment of the ulnar nerve is identified posterior to the internal intermuscular septum, after it has left the neurovascular bundle. Before disturbing the circumferential relationship of the nerve by complete isolation, in both upper and lower positions, the center of its lateral quadrant should be carefully marked with accurately placed identification sutures. The dissection of the nerve may now progress to the point of lesion. If the identification sutures previously placed are found to be some distance from the lesion, as the dissection progresses they should be supplemented with additional sutures, carefully observing the surface markings of the nerve. Much difficulty is experienced in the dissection of the neurovascular bundle, particularly when it is invaded with scar tissue, due to bleeding from numerous venous and arterial radicals. This difficulty may in a large measure be obviated by isolation of the basilic and brachial veins below, and the application of permanent or temporary constriction. Arterial hemorrhage may be controlled by isolating the brachial artery above and applying a tape which may be adjusted to control its circulation while branches are being ligated or accidental wounds in the arterial wall repaired.

Defects in the continuity of the ulnar trunk in the arm, if of a magnitude not correctable by primary nerve stretching, will call for transposition of the

nerve from behind the medial condyle of the humerus to a more ventral position, after which advantage may be taken of elbow flexion-relaxation. When this procedure fails to overcome the defect, the ulnar nerve should be freely mobilized in the axilla and recourse taken to the two-stage operation.

SURGERY IN THE REGION OF THE INTERNAL HUMERAL CONDYLE

The ulnar nerve, as it passes behind the internal humeral condyle is exposed to frequent trauma. Its involvement in war injuries is second only to lesions of the musculospiral. Its lateral surface, being in direct contact with the bone, and its medial surface being very superficial, renders it particularly susceptible to trauma.

PROGRESSIVE PERIPHERAL ULNAR PARALYSIS

Severe injury to the ulnar nerve usually results in complete immediate paralysis, while frequently repeated slight trauma will result in a gradual progressive type of peripheral paralysis, in which sensation is slowly lost and atrophy of the intrinsic hand muscles supervenes. The ulnar nerve, because of its exposed position behind the medial humeral condyle, is commonly the recipient of frequent mild degrees of trauma, though of sufficient intensity to institute a gradual compression paralysis, due to the production of intraneural scar tissue. Occasionally this type of ulnar paralysis will develop years after a trauma to the medial condyle or the elbow joint. The original trauma may escape memory, but is probably responsible for the institution of some anatomic change in the bone proximal to the nerve, or for a thickening of the aponeurotic fascia covering the nerve, producing compression or intensifying the effect of ordinary trauma to this region.

In lesions of this type, the ulnar nerve should be transposed from its exposed position behind the humeral condyle to the less traumatized region anterior to the condyle. This procedure will usually suffice to correct most progressive peripheral lesions, though when the nerve is found to be indurated, its sheath should be opened and the bundles subjected to internal neurolysis. The nerve sheath is allowed to remain open for its decompressive effect.

Exposure

The surgery of the ulnar nerve in the region of the internal condyle necessitates exposure in its lower humeral and upper forearm course. With the arm fully abducted and in external rotation, the forearm flexed and in extreme supination, a curved incision is carried from the junction of the middle and lower third of the arm, beginning along the medial border of the biceps, following the course of the nerve downward behind the internal condyle to the forearm where it follows its anterior ulnar border to the junction of its upper and middle third. In the line of this incision, the deep fascia is divided and the nerve identified distal and proximal to the lesion. In its lower humeral course, the nerve will be found, after having penetrated the internal intermuscular septum, following the posterior border of this structure, lying upon the internal head of the triceps or covered by its superficial fibers. It is accompanied by the inferior profunda artery which may usually be separated from the nerve

to the internal condyle, where ligation will be required, as in this region the artery and its venæ comites anastomose freely with the ulnar recurrent artery and vein. The preliminary ligation of these vascular structures, both above and below the internal condyle, where they lie in direct contact with the nerve, will greatly enhance the dissection. The ulnar collateral branch of the musculospiral nerve, supplying the medial head of the triceps, follows a course along the posterior border of the internal intermuscular septum in close relation to the ulnar nerve and care should be used in avoiding its injury. At the internal medial condyle, the ulnar nerve is protected by a thick aponeurotic membrane stretching from the medial condyle to the olecranon, as they are occasionally adherent. Before the relationship of the nerve has been disturbed in its bed, it should be carefully marked by sheath identification sutures to prevent torsion during subsequent suture. The nerve, after being uncovered in its course posterior to the medial condyle, will be found entering the foramen by passing under the tendinous arch, connecting the two heads of the flexor carpi ulnaris. The fibers of this arch are divided and the line of cleavage between the two heads of the muscle separated for a short distance, exposing the nerve in its passage below this muscle, where it lies upon the muscular fibers of the flexor profundus. In the region of the condyle and below, important branches will be found innervating the flexor carpi ulnaris and the ulnar half of the profundus digitorum; these motor branches spring from the medial and posterior quadrant of the nerve. The branches to the flexor carpi ulnaris leave the ulnar trunk somewhat higher than those to the profundus—usually about the level of the condyle. The fibers innervating the flexor carpi ulnaris may leave the nerve trunk as a single bundle, subsequently dividing to supply its two heads, or these branches may leave the parent trunk after their division. If the ulnar sheath is opened, however, they will be found united into a single branch or bundle, and may be followed some distance above the internal condyle. The lower branch, innervating the ulnar half of the flexor profundus digitorum, may likewise leave the nerve trunk as a single branch, or after its division. Within the nerve trunk, however, it may be followed as a single bundle some distance above the condyle, where it will be found to join with the bundle containing the fibers to the flexor carpi ulnaris. After these two bundles have combined, their intraneural course may frequently be followed as high as the middle third of the arm. The intraneural dissection of these branches is extremely important in transposing the nerve to a position anterior to the humeral condyle, in the correction of continuity defects—it is our only means of preserving these branches during such a procedure. Occasionally, in lesions in the region of the medial condyle, these motor branches may be found divided; and if they can not be identified and repaired, provision should be made for ulnar profundus paralysis by dividing the two medial profundus tendons above the wrist and uniting them with the two lateral profundus tendons which are supplied by the median nerve.

TRANSPOSITION OF THE ULNAR NERVE

Transposing the ulnar nerve from its position behind the internal humeral condyle to the anterior surface of the elbow is a valuable procedure in over-

coming defects in the continuity of the nerve; it is also indicated in progressive peripheral ulnar paralysis in which the nerve is subjected to trauma when occupying its normal position. In overcoming defects, transposition of the ulnar nerve will shorten its course and render it susceptible to flexion-relax-

FIG. 183.—Ulnar nerve, showing scar tissue as found at operation. Nerve exposed by splitting the two heads of flexor carpi ulnaris; exposure of distal and proximal segments. Identification sutures placed. A, Medial epicondyle; B, olecranon; C, ulnar nerve, proximal segment; D, flexor carpi ulnaris, ulnar head; E, ulnar nerve, distal segment; F, flexor carpi ulnaris, humeral head; G, internal intermuscular septum

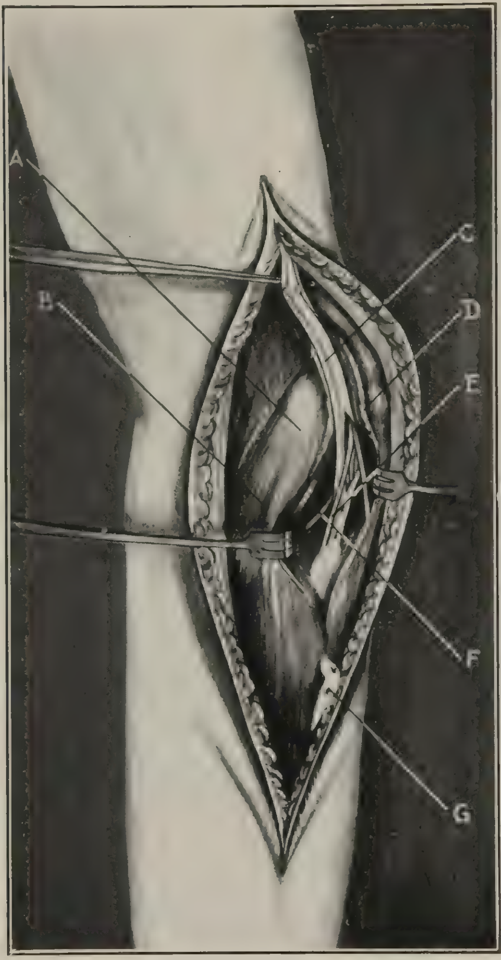

FIG. 184.—Ulnar nerve exposed above medial humeral condyle preparatory for transposition anterior to the condyle. Intraneural exposure and mobilization of branches to ulnar half of flexor sublimis digitorum and flexor carpi ulnaris; mobilization of branches should be carried at least 3 cms. above condyle. A, Medial epicondyle; B, flexor carpi ulnaris, humeral head; C, ulnar nerve; D, wall of ulnar canal; E, branch to flexor carpi ulnaris; F, branch to flexor profundus digitorum; G, ulnar nerve, distal segment

ation of the elbow, when defects in the forearm of three or four inches may be readily overcome.

The incision for ulnar transposition follows the course of the nerve from the middle of the arm to the middle of the forearm. The deep fascia is divided in the line of the skin incision and the nerve exposed throughout the length

of this incision, care being taken to place a sufficient number of identification sutures to assure alignment of the nerve, if suture is required. The anterior skin flap containing the fat of the superficial fascia is reflected, exposing the medial border of the biceps and its tendon. The ulnar nerve is now followed upward to the middle third of the arm where it penetrates the internal intermuscular septum; the septum is divided and the nerve made to pass along its ventral border, following the course of the neurovascular bundle to the antecubital fossa. To transpose the nerve below the medial condyle so that it will follow a straight line down the arm and forearm, its motor branches to the flexor carpi ulnaris and the profundus digitorum must be mobilized some distance up the nerve trunk to prevent stretching and tearing in transposing the nerve. The nerve in its transposed position passes over those muscles arising from the medial condyle. If the cutaneous structures in this region have been well preserved and contain sufficient subcutaneous fat, the writer

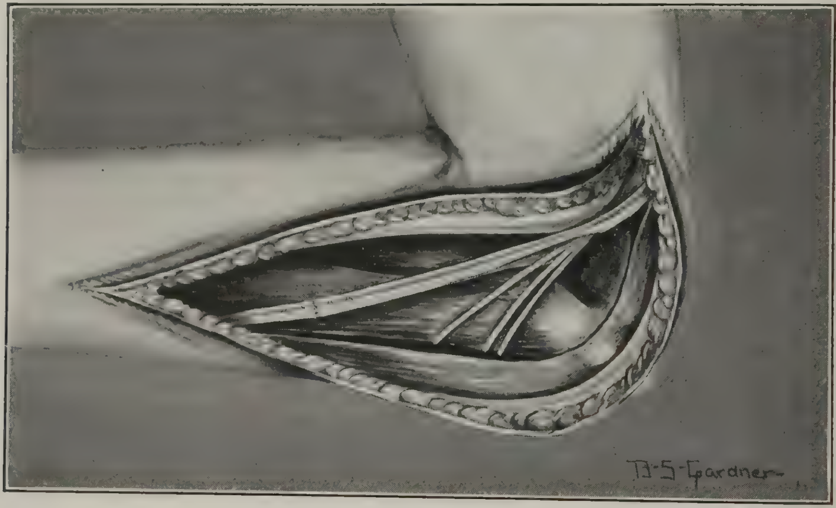

FIG. 185.—Ulnar nerve transposed; defect overcome by transposition and flexion-relaxation of elbow; branches preserved through mobilization

prefers transplanting the nerve in this superficial position, where it is covered merely by the fat of the superficial fascia. Some operators, however, prefer directing the nerve through a muscular tunnel below the common heads of origin of the superficial muscles springing from the medial condyle, the bed of the nerve being the flexor profundus digitorum. This may be accomplished in two ways, depending upon the ability to preserve the motor branches to the flexor carpi ulnaris and profundus digitorum. If the motor branches have been sacrificed, the nerve is passed through a tunnel between the sublimis and profundus digitorum, made by passing forceps between these muscles, widening the tunnel and drawing the free end of the nerve through. The second method consists in dividing the superficial muscles close to their origin to the medial condyle, placing the nerve in the cleft and resuturing the muscles above it. This has the disadvantage of possibly interfering with the nerve supply of normal muscles, and also of inflicting additional trauma to the

structures surrounding the nerve. While the tunneling procedure is less apt to injure the nerve supply of adjacent muscles, it undoubtedly invites an excess of scar tissue by virtue of the trauma inflicted.

EXPOSURE IN THE MIDDLE AND LOWER THIRDS OF THE FOREARM

An incision extending from the radial side of the pisiform bone toward the medial condyle will follow the course of the ulnar nerve in the forearm. After the deep fascia has been divided, the tendon of the flexor carpi ulnaris is identified. It will be remembered that the lateral or radial border of the flexor carpi ulnaris is tendinous for some distance up the forearm, while from its medial or ulnar border muscular fibers radiate almost as far down as the wrist joint. The ulnar nerve, accompanied by the ulnar artery and its venæ comites, lies beneath the radial border of the flexor carpi ulnaris tendon and to the ulnar side of the flexor sublimis digitorum. Following upward the cleft between these muscles, the ulnar nerve will be found resting upon the flexor profundus digitorum and covered by its thin sheath. It is advisable to first identify the nerve in the region of the wrist, after which it may be followed upward by separating the loose attachment between the flexor carpi ulnaris and the flexor sublimis digitorum: the identification of the line of cleavage between these muscles is facilitated by following up the radial tendinous edge of the flexor carpi ulnaris. If difficulty is encountered in exposing the proximal end of the nerve, it may be readily identified at the medial condyle, which it leaves to pass between the two heads of the flexor carpi ulnaris. These two heads may be separated for some distance and the nerve followed as it passes below the belly of the humeral head, which latter may be conveniently elevated by tape retraction, its radial border having been previously separated from the sublimis and palmaris longus. In the upper part of the middle third of the forearm, the ulnar artery joins the nerve and follows it throughout the remainder of its course. In the middle third of the forearm a small palmar cutaneous branch is given off, which follows the ulnar artery down the forearm and passes over the annular ligament: this branch is unimportant and may be sacrificed with impunity. About the lower third of the forearm, though at times much higher, a large dorsal cutaneous branch arises from the medial side of the ulnar trunk and passes under the tendon of the flexor carpi ulnaris to supply the integument of the ulnar dorsal side of the hand and fingers. This branch is occasionally of rather large size and must not be confused with the main ulnar trunk. It follows a relatively long intraneural course and its preservation is important, as it supplies sensation to the much traumatized ulnar border of the hand and little finger.

Lesions of the ulnar nerve in the lower two-thirds of the forearm are commonly associated with more or less tendon injury, which should be repaired before the nerve is sutured. If sublimis or profundus tendons on the ulnar side are injured, they should be freed of all scar tissue and reunited if possible. If suture of the divided tendons is not possible, they should be anastomosed to intact sublimis or profundus tendons, and their bellies above freed of scar and likewise united. Occasionally the palmaris longus may be transplanted into the distal end of the divided sublimis tendons.

SURGERY OF THE ULNAR NERVE IN THE PALM

The ulnar nerve enters the palm by passing through the annular ligament in a compartment of its own along the radial border of the pisiform bone, and in the palm divides into its two terminal branches—a superficial branch, mainly sensory, and a deep branch, principally motor to the ulnar intrinsic hand muscles. These terminal ulnar branches do not lend themselves favorably to surgical repair, though as with the median, occasional instances will be found where extremely localized injuries involving the nerve with small defects will permit repair.

FIG. 186.—Branches of ulnar nerve in hand. A, Digital cutaneous branch, fourth and fifth fingers; B, digital cutaneous branch, fifth finger; C, palmaris brevis; D, motor branch to intrinsic muscles; E, ulnar nerve; F, ulnar artery; G, palmar fascia; H, palmaris longus tendon; I, annular ligament

EXPOSURE

Exposure is made through an incision extending from the radial border of the pisiform bone to the interspace between the fourth and fifth fingers. The nerve is localized at the wrist and followed into the hand by dividing the annular ligament, the palmar fascia and the palmaris brevis, exposing the flexor brevis minimi digiti and the opponens of the little finger. By retracting the ulnar border of the incision, the deep branch may be followed and exposed as it passes in a cleft between the flexor brevis and abductor, which muscles require careful identification as they are important landmarks. If the interspace between these muscles is spread, exposing the opponens, the nerve may be followed to a point where it penetrates the latter muscle. After penetrating the opponens, the deep palmar branch passes below the flexor tendons and in this region is practically inaccessible. The superficial palmar branch may be identified by its superficial position and by the distribution of its digital branches. Occasionally it is possible to effect individual suture of these digital branches, their arrangement being similar to the median digital branches.

In attempting repair of the small cutaneous or motor branches of the median or ulnar nerve in the hand, the operator should proceed with extreme care and a full appreciation of the difficulties involved, in that the disability resulting from the inflicted surgical trauma may be greater and overshadow the original disability.

DEFECTS IN CONTINUITY

Because of the passage of the ulnar nerve posterior to the internal humeral condyle, it does not lend itself to flexion-relaxation of the elbow joint. In fact, flexion of the elbow joint tends to stretch the nerve, which normally is relaxed by forearm extension. It therefore becomes necessary in most ulnar defects to resort to transposition of the nerve from its posterior position behind the internal condyle to an anterior position, by which the operator utilizes the elongating effect of directing the nerve from an angular to a straight course, and which also permits an extensive relaxation of the nerve during forearm flexion.

Defects in the forearm up to 3 or 4 inches may be overcome by utilizing transposition of the ulnar nerve with flexion-relaxation of the elbow. Defects of greater magnitude in the forearm require extensive mobilization of the nerve, which should be continued to the wrist below and to the upper third of the arm above, when another inch may be added by ulnar flexion of the wrist and abduction of the arm. If the surgeon, having availed himself of these procedures, finds difficulty in obtaining end-to-end approximation, he must then resort to the two-stage operation, described under general technique. An endeavor should always be made to preserve the motor branches at the elbow, though they may be sacrificed if their extensive intraneural mobilization fails to give sufficient relaxation to the nerve. If it becomes necessary to sacrifice the motor branches to the flexor carpi ulnaris and ulnar half of the profundus digitorum, the function of the profundus tendons may be maintained by transplanting them at the wrist into the two remaining active profundus tendons.

The surgeon is rarely justified in sacrificing the dorsal cutaneous branch of the ulnar for relaxation purposes. If it is found to interfere with ulnar mobilization, it should be freed as far as possible along the ulnar border of the forearm. Sacrifice of the dorsal cutaneous branch involves a permanent anesthesia of the ulnar border of the hand and little finger, which may in itself necessitate amputation of these parts, because of the constant irritation of trophic or traumatic sores.

In the arm, large defects of the ulnar nerve necessitate exposure well up into the axilla and well down into the forearm. Flexion-relaxation is inhibited in upper defects of the nerve by the motor branches at the elbow, and to obtain its full effect, sacrifice of these branches is usually necessary. In transposing the ulnar nerve for the correction of defects, the surgeon should assure himself that the nerve is freely mobilized in the region of the internal intermuscular septum. Ulnar defects, which can not be overcome by stretching, transposition, and flexion-relaxation of the elbow, wrist, and shoulder are probably beyond repair, though in such cases the surgeon should not neglect the possibilities of a successful graft, but grafting may be used only as a procedure of last resort.

SECONDARY SUTURES

Surgery of the ulnar nerve gives perhaps more unsatisfactory results than any other nerve, primarily because of failure in regeneration of the ulnar intrinsic hand muscles. In the writer's experience, regeneration of the inter-

ossei muscles is absent, after four years, in 94 per cent of ulnar sutures. These delicate, highly specialized intrinsic hand muscles reach an extreme degree of muscle degeneration in a comparatively short period. In several cases of ulnar paralysis, resulting from compression lesions, in which there has been a satisfactory restoration of ulnar sensation following neurolysis, the ulnar intrinsic hand muscles have remained paralyzed where the uncorrected lesion had existed beyond one year. The writer has observed a number of cases in which some function had returned in the muscles of the hypothenar eminence and the adductor pollicis, though no action could be demonstrated in the interossei.

The restoration of function in the ulnar portion of the profundus digitorum and the flexor carpi ulnaris occurs in approximately 60 per cent of cases, following suture. In most cases of ulnar suture in which there has been some degree of axis cylinder regeneration, some return of sensation is found in the ulnar border of the hand and little finger. This sensation, in most instances, after a period of two years is nondiscriminative in character, all types of sensation being described as tingling. Usually after the third year, the power to discriminate between various sensations gradually returns to a greater or lesser degree, but usually sufficient to afford protection to this region of the hand.

In view of these facts, a failure of interossei regeneration should not be considered as defective regeneration beyond our usual experience, and this defect does not call for secondary surgical intervention. The failure of sensory restoration in the ulnar region is indicative of defective regeneration and does not call for intervention. In considering defective regeneration in the ulnar nerve, sensation deserves the greatest attention. Any hope of regeneration, to a satisfactory degree, in the intrinsic hand muscles may be practically abandoned for an uncorrected paralysis of one year's standing. Paralysis of the flexor carpi ulnaris and ulnar half of the profundus digitorum is productive of no great disability and the slight disability existing from their paralysis may readily be overcome by tendon transplantation.

DETERMINATION OF REGENERATION

The examiner must depend entirely upon Tinel's sign for information during the early stages of ulnar regeneration following suture. After six months, if formication is not elicited in the distal segment of the nerve, it should be considered as defective neuraxon regeneration, and secondary surgical intervention is indicated.

Certain precautions must be taken in the presence of much scar tissue in the region of the suture, in eliciting this reaction. The tugging of a scar upon a neuroma or suture line may elicit the reaction of formication in a region below the regenerated nerve fibers. When Tinel's sign is elicited throughout the distal nerve trunk and this reaction is intense, it may be prognosticated that sensory fibers are regenerating satisfactorily, and the patient assured of some degree of sensory restoration. A persistent loss of sensation in the ulnar region with a sensitive suture line, giving evidence on palpation of neuroma formation, suggests defective suture and secondary exposure is indicated.

The writer has observed several instances in which there was no evidence of regeneration following a neurolysis of the ulnar nerve. Such failures, frequently commented upon by other writers, need not, necessarily, call for resection of the nerve and suture, unless an internal neurolysis has demonstrated a complete blocking of the scarred trunk, with obliteration of motor bundles. These defective end results, following neurolysis, are usually due to imperfect surgical judgment at the time of operation, when an external neurolysis was probably the extent of the operation; the real compressive factors evidently were overlooked.

In complete persisting failure of regeneration, and in irreparable defects, where the anesthetic area is constantly being subjected to trauma, and suffering trophic disturbances, amputation of the little finger offers the only solution. Occasionally this amputation must also include the ulnar metacarpal region. A very deforming fibrous griffe may be allowed to develop in the little finger, greatly diminishing the usefulness of the hand, which also may justify amputation.

COMBINED LESIONS OF MEDIAN AND ULNAR NERVES

The close anatomic relationship existing between the median and ulnar nerves in the middle and upper thirds of the arm makes their combined lesions comparatively frequent. Less often are combined lesions of these nerves experienced below the lower third of the arm, where they pursue a divergent course, though combined lesions are by no means uncommon in extensive gunshot injuries of the forearm. The importance of combined median and ulnar lesions is emphasized by the seriousness of the resulting diasbility, in which all of the extrinsic and intrinsic flexion power of the fingers is lost, as well as the power of pronation; this paralysis, combined with complete anesthesia of the palm and fingers, renders the extremity practically useless.

The surgical repair of combined median and ulnar lesions differs in no respect from the individual repair of these nerves, each of which should be treated surgically as an individual unit. The necessity for a separate consideration of combined median and ulnar lesions is advisable, however, because of supplementary surgical procedures indicated in a total absence of or defective nerve and muscle regeneration.

In the great majority of instances following a successful end-to-end approximation in both median and ulnar nerves (if due respect has been given to the prevention of torsion during suture) there will be a restoration of voluntary motor power in the pronators, wrist flexors, and extrinsic digital flexors, with a gradual return of sensation; the total anesthesia of the fingers is replaced at first by a nondiscriminative type of anesthesia, which later, after two or three years, is slowly supplemented with the power of tactile localization and discrimination. This degree of functional restoration following the suture of these nerves is probably as complete as may reasonably be expected. The residual disability is confined to a loss of function in the intrinsic hand muscles, expressed by: (1) Loss of opponens function of the thumb; (2) inability to flex the metacarpophalangeal joints; (3) loss of extension of the interphalangeal joints with hyperextension of the metacarpophalangeal joints.

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These disabilities produce a deformity commonly characterized as the "claw hand" of complete intrinsic hand-muscle paralysis. The long flexors of the fingers are unable to conjointly flex the metacarpophalangeal joints and terminal phalanges; attempts at flexion are followed by a rolling up of the terminal phalanges, in which the nails, instead of the palmar surface of the fingers meet the palm, due to the fact that flexion of the metacarpophalangeal joints does not occur synchronously with phalanx flexion, and when flexion does occur at the metacarpophalangeal joints it is only after the interphalangeal joints are completely flexed.

The thumb disability consists in the loss of opponens action, and though flexion of the distal phalanx is restored through the long flexor of the thumb, this member rests against the radial border of the hand, and normal thumb and index finger opposition ("pinch action") is replaced by a very defective and ineffectual approximation, in which the nail of the thumb meets the radial side of the index finger, objects being held between the thumb nail and this finger very much as a small boy holds a marble for shooting.

The extensor communis digitorum is capable of extending the terminal phalanges when the long flexors are completely paralyzed, but it seems to lack this power when they are active. Its principal action is extension at the metacarpophalangeal joints. In intrinsic hand-muscle paralysis the fingers can not be completely extended; during attempts at extension the terminal phalanges remain partially flexed, while the metacarpophalangeal joints are hyperextended. The interossei, by virtue of their insertion into the extensor tendons beyond the metacarpophalangeal joints, accomplish terminal phalangeal extension; in this they are assisted by the lumbricales, which also by virtue of their origin from the tendons of the profundus digitorum and their insertion with the interossei into the extensor tendons, near the center of the first phalanx, prevent hyperextension of the metacarpophalangeal joints, as the lumbricales are flexors of these joints and antagonists to the extensor communis digitorum. The function, therefore, which we wish to restore in intrinsic hand-muscle paralysis is the opposing action of the thumb, and flexion of the metacarpophalangeal joints, with extension of the terminal phalanges, metacarpophalangeal flexion is particularly important in the index finger.

For the restoration of opponens function, or rather the maintenance of the thumb in the opponens position, Major Baldwin attempted arthrodesis of the first metacarpophalangeal joint and fixed it in an opposed position at an angle of 60 degrees, which is practically the normal angle existing between the first and second metacarpals during pinching action. This operation, though restoring the opponens position of the thumb and greatly improving its function, has a distinct disadvantage; it does not permit abduction and extension, the thumb remaining continuously opposed over the palm, in which position it is like the drop thumb of extensor paralysis and is frequently in the way.

The writer devised and practiced a tendon transplant for the restoration of opponens function in the thumb, which duplicates this action perfectly, at the same time allowing its complete extension. The procedure consists in directing the short extensor tendon of the thumb through a tunnel under the fat of the

superficial fascia; from the palm it is directed under the annular ligament to the wrist where it is anastomosed to the palmaris longus. The end results of this procedure have been observed in a series of cases for a period of more than three years. In each instance the opposing action of the thumb has remained excellent and has gradually increased in power with the development of the palmaris longus muscle.

TENDON TRANSPLANTATION FOR RESTORING OPPONENS ACTION TO THE THUMB IN INTRINSIC HAND-MUSCLE PARALYSIS

This procedure is conducted entirely under local anesthesia, which assists materially in hemostasis; it also permits the testing out of the transplant during operation, by voluntary contraction of the palmaris longus, the patient having been previously instructed in the contraction of this muscle.

Technique

a. A midventral wrist incision is made over the course of the palmaris longus tendon, extending from the base of the palm just below the annular ligament, upward for a distance of about 7 cm. The palmaris longus tendon is identified and freed, and its attachment to the palmar fascia divided, after it has passed over the annular ligament. The median nerve lies immediately below the palmaris tendon and is usually exposed with the retraction of this tendon. A pair of blunt-curved forceps is now passed under the annular ligament at this point, and made to emerge below its palmar border, by penetrating the palmar fascia, the forceps being spread to enlarge the opening. The opening in the palmar fascia is enlarged sufficiently, by excising its edges, to prevent subsequent constriction of the transposed extensor tendon, which is passed through this opening.

b. A dorsal thumb incision from the base of the proximal phalanx extends to the radiocarpal articulation, bisecting the "anatomical snuffbox." To the palmar side of this incision the short extensor tendon is located as it lies in a separate sheath in juxtaposition with the dorsal border of the tendon of the extensor ossis metacarpi pollicis. The long extensor tendon, which lies to the dorsal side of the incision, must not be confused with the short extensor tendon—traction on the tendon of the long extensor produces extension of the distal phalanx. The sheath of the short flexor is opened and the tendon followed downward to the metacarpophalangeal joint of the thumb. This short flexor tendon is divided about 10 cm. above its insertion, where it lies in close approximation with the tendon of the extensor ossis.

c. A tunnel is now maed between the lower ends of the two incisions, undermining the fat of the superficial fascia in a line connecting the annular ligament and the metacarpophalangeal joint of the thumb. Through this tunnel a pair of forceps is passed from the ventral to the dorsal incision and the divided end of the extensor brevis pollicis tendon caught and drawn through the tunnel to the opening in the palmar fascia. Its end is then grasped by the previously placed subannular forceps, drawn through the opening in the

palmar fascia under the annular ligament to the wrist, where it is anastomosed to the palmaris longus tendon, with sufficient tension to produce marked abduction and opposing rotation of the thumb. When the palmaris longus is absent, as it is in approximately 20 per cent of cases, the transposed extensor tendon may be passed through a slit in the flexor carpi radialis tendon

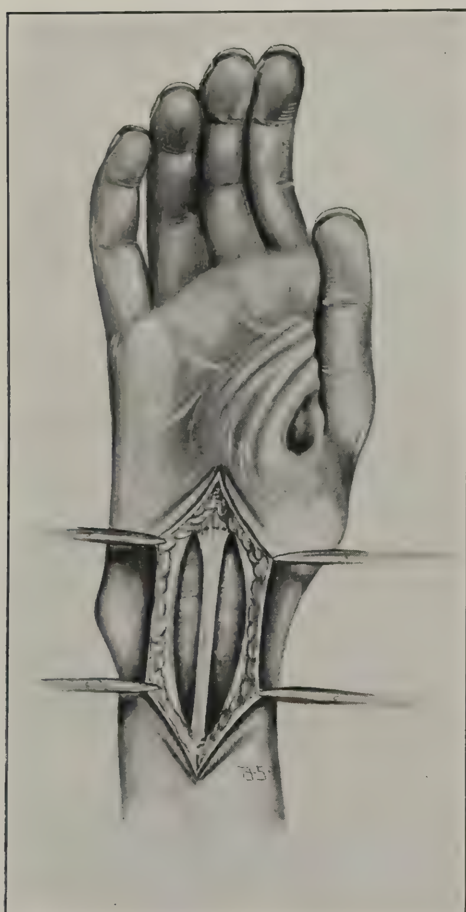

FIG. 187.—Tendon transplant for restoring opponens position and function to the thumb in intrinsic hand muscle paralysis; exposure of palmaris longus tendon

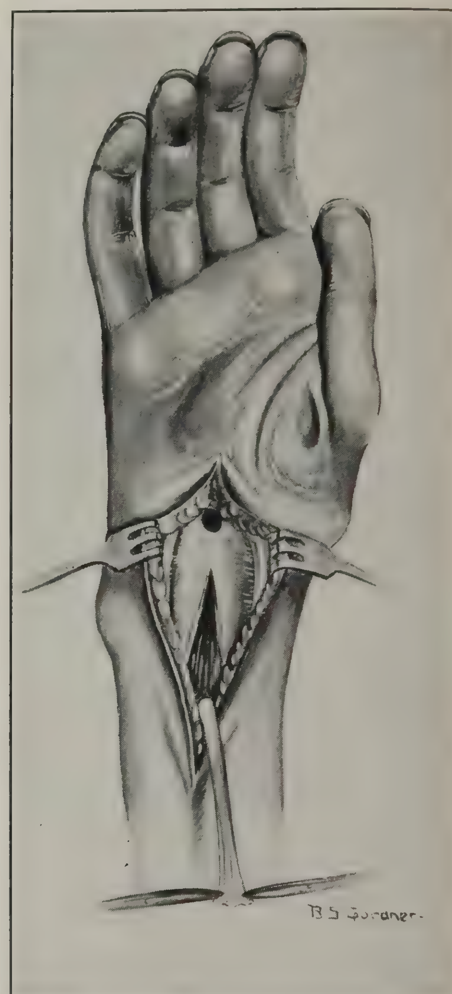

FIG. 188.—Tendon transplant for restoring opponens position and function to the thumb in intrinsic hand muscle paralysis. Tendon of palmaris longus divided; opening made in palmar fascia at upper part of annular ligament

and sutured, without division of the tendon of the latter muscle. (In the writer's experience, more satisfactory end results have followed transplantation into the palmaris longus.) The thumb now lies across the palm in an opposed and abducted position and with the wrist slightly flexed; the skin incisions are closed, and the hand dressed with the thumb and fingers grasping an unrolled

bandage, which tends to maintain the thumb in the desired position. The fist, with the wrist flexed, is firmly supported with suitable bandages or splinting to insure the maintenance of this position.

The subsequent treatment is conducted along lines common to the after-treatment of all tendon transplantations. Reeducation is, as a rule, not difficult, and a few demonstrations will usually be found sufficient to institute effective opponens action of the thumb in individuals of ordinary intelligence. This transplant is synergetic, in that forceful prehension of the thumb is accompanied normally by contraction of the palmaris longus.

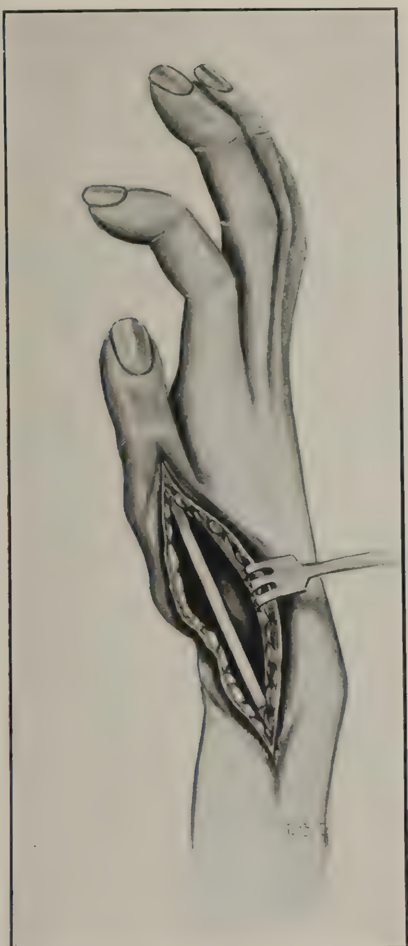

FIG. 189.—Tendon transplant for restoring opponens position and function to the thumb in intrinsic hand muscle paralysis; exposure of short extensor of the thumb

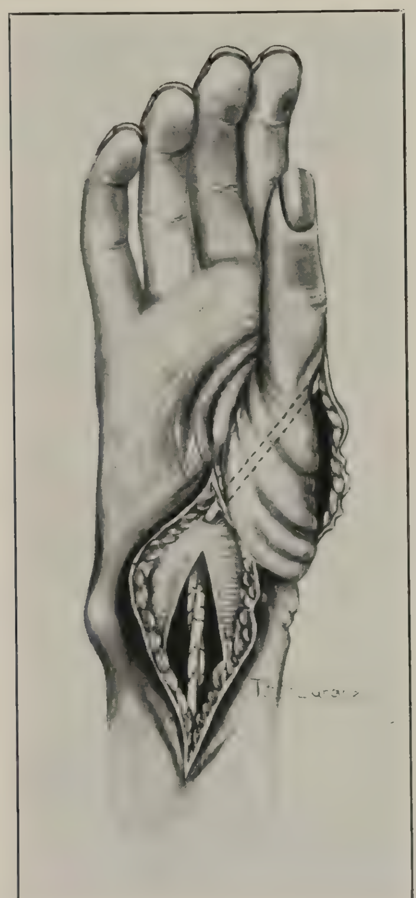

FIG. 190.—Tendon transplant for restoring opponens position and function to the thumb in intrinsic hand muscle paralysis. Passage of the divided short extensor tendon through a subcutaneous tunnel in the thenar eminence and through opening in palmar fascia, where it passes below the annular ligament and is anastomosed to the palmaris longus tendon, holding the thumb in the opponens position

TENDON TRANSPLANTATION FOR RESTORING METACARPOPHALANGEAL FLEXION AND EXTENSION OF THE TERMINAL PHALANGES (LUMBRICALES AND INTEROSSEI FUNCTION)

For the restoration of metacarpophalangeal flexion, Stiles devised an ingenious operation in which he alters the insertion of the flexor sublimis digitorum tendons, rendering them flexors of the metacarpophalangeal joints by suturing them to the exterior communis tendons distal to the knuckle, which makes them also extensors of the interphalangeal joints, thus causing the flexor sublimis digitorum to subserve the function of both interossei and lumbricales. This procedure may be carried out on each finger or it may be limited to the index.

TECHNIQUE

a. Through a mid-dorsal incision, the skin and fascia are divided, and the common extensor exposed. The insertions of the interossei and lumbricales into its lateral aspect are identified and freed.

b. An incision is made along the flexor aspect of the digit from the transverse palmar crease to the distal interphalangeal joint, exposing the flexor sheath, which must not be opened through the line of incision. About the base of the metacarpophalangeal joint, the sublimis tendon divides to permit the passage of the profundus tendon. The lateral and medial slips of the tendon then pass forward to be attached into the sides of the middle phalanx. Near their insertion a small incision is made through the sheath of each tendon slip and the tendon divided. Next the tendon is identified opposite the metacarpophalangeal joint, where it has just begun to split; an opening is made in the sheath at this point, and each tendon slip pulled out of its sheath. Stiles emphasizes the importance, in making these openings in the sheath, of not disturbing the small bands which hold the profundus tendon in place opposite each phalanx, "otherwise the tendon will stand forward under the skin like a bowstring when the patient attempts to flex the finger, and will lose its pull on the terminal phalanx." Each half of the sublimis tendon is now passed through a subcutaneous tunnel on each side of the digit to the dorsal incision and threaded through an opening made in the expanded portion of the extensor sheath which receives the insertion of the interossei and lumbricales. The two tendons are sutured in this position with linen, with the knuckle flexed at right angles and the interphalangeal joints straight. Any excess of tendon is cut away and the raw ends buried by a suture through the two sides of the communis. Both wounds are closed and the fingers fixed by pads and bandages in a position of metacarpophalangeal flexion and terminal phalanx extension.

IRREPARABLE DEFECTS OF THE MEDIAN AND ULNAR NERVES

An irreparable defect of the median and ulnar nerves is attended with such a degree of disability to the extremity that it may be considered as permanently useless, unless some flexion function can be restored to the fingers through tendon transplantation. The accompanying anesthesia, however, seriously diminishes the functional usefulness of the hand, even though digital flexion is regained through tendon transplantation. Before resignation is

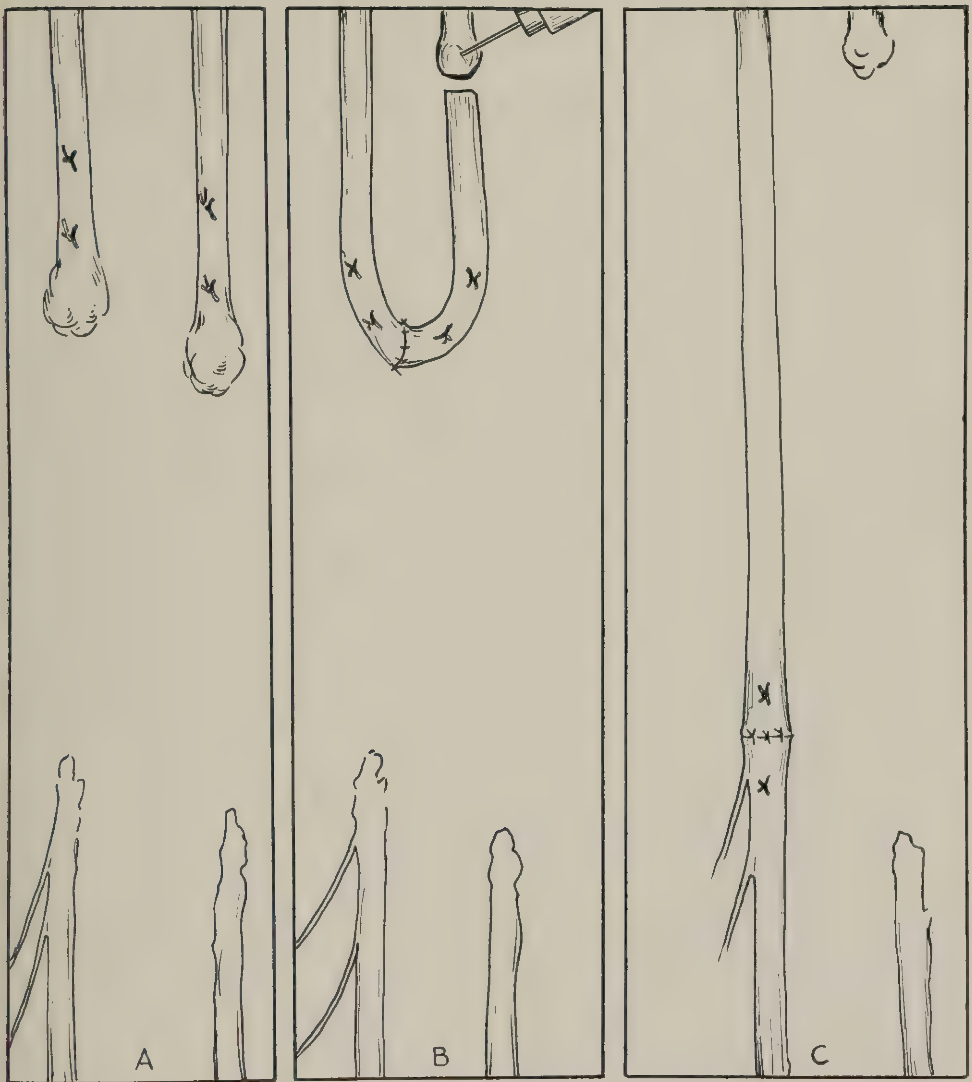

Fig. 191.—Diagrammatic explanation of viable neuroplastic transplant for filling of median defect in irreparable lesion of both median and ulnar nerves. A, Showing large irreparable defect of both median and ulnar nerves; the upper segments of both nerves are marked with identification sutures. B, Proximal end of both nerves united by end-to-end suture. Ulnar nerve divided to permit degeneration of fibers, the central end of which is injected with alcohol to prevent regeneration of ulnar fibers in that portion of ulnar trunk which is to be used later as a viable transplant. C, Second stage of operation, showing transplant which now contains regenerated median fibers turned down and approximated to the end of the distal segment of the median, overcoming the defect, the ulnar nerve being sacrificed to repair the median

made to an irreparable median and ulnar defect (the two-stage operation for nerve repair and grafts having failed), the surgeon should consider the possibility of preserving some type of sensation in the fingers by nerve anastomosis. Harris suggested anastomosing the radial nerve to the distal stump of the median. This procedure may be followed by some restoration of sensation in the median sensory area of the hand and fingers; this sensation, however, is attended with dorsal localization, and although it protects the fingers by replacing anesthesia with a defectively localized sensibility, it contributes little to functional usefulness.

SACRIFICE OF THE ULNAR NERVE AS A VIABLE NEUROPLASTIC TRANSPLANT FOR THE REPAIR OF A MEDIAN DEFECT

When all hope has been definitely abandoned of effecting approximation in both median and ulnar nerves, the disability may be diminished by using the ulnar nerve as a viable neuroplastic transplant for bridging the defect in the median, in the hope of restoring at least median sensation, and possibly function, in the extrinsic muscles of the hand. If this motor restoration is possible, opponens function and metacarpophalangeal flexion may be restored by tendon transplantation, and a very useful hand provided; if it is found impossible to restore motor function, flexion of the digits may be restored to some degree by tendon transplantation and some usefulness, at least, regained.

Technique

First stage.—The proximal ends of both median and ulnar nerves are exposed, the scar tissue and neuroma resected, after which they are carefully approximated, following the usual technique of end-to-end suture, extreme care being taken to prevent torsion of the nerve trunks in this approximation. This procedure results in the formation, after anastomosis, of a loop uniting the proximal ends of these nerves. Without disturbing the bed of the ulnar nerve any more than necessary, it is exposed some distance above the anastomosis and divided to permit Wallerian degeneration of the nerve fibers in that portion of the ulnar trunk which at the second operation will be turned down to meet the distal end of the median as a transplant. This transplant should be slightly longer than the defect—if the defect be 5 inches, the ulnar nerve should be divided 5½ or 6 inches above its anastomosis to the median. The upper end of the divided ulnar trunk is injected with alcohol or treated after the manner of amputation neuromas, to prevent regeneration of ulnar fibers down the transplant. It is essential in this procedure to conserve in every way the nutrition of that portion of the ulnar trunk which is being used as a transplant; hence the necessity of not disturbing its bed. The median fibers, in regenerating, will now pass around the loop and follow the transplant upward, and if sufficient time be allowed they will form a neuroma at the upper end of the transplant where the ulnar nerve was divided. Inasmuch as regeneration occurs, approximately, at the rate of 1 inch per month, the second operation should be postponed until the median fibers have completely traversed the transplant; in a 5-inch transplant the second operation should be planned at the end of the sixth month, allowing a month of grace.

Second stage.—Both proximal and distal segments of the median nerve are now exposed; in the lower segment the center of the ventral quadrant is marked by identification sutures before disturbing its relations; in the upper segment the loop of anastomosis between the median nerve and the transplant is now carefully exposed and the transplant followed upward to its end, where identification sutures are placed in the center of its exposed ventral quadrant. The transplant is freed by careful dissection and turned down to meet the end of the distal segment of the median; the scar tissue is now resected from both ends of the nerve and approximation effected, with strict care toward the prevention of torsion. The selection of a satisfactory bed for the transplant is important.

In the above procedure the defect in the median nerve is filled by a viable transplant through which median fibers have regenerated and is far more likely to prove successful than nonviable grafts.

When the ulnar nerve has been sacrificed and the ulnar portion of the hand and little finger is the subject of traumatic and trophic sores amputation is indicated. If, however, the skin of the ulnar portion of the hand remains in good condition through proper protection, restoration of sensation can be obtained in certain instances by anastomosing the radial nerve to the ulnar.

TENDON TRANSPLANTATION FOR COMPLETE FLEXOR PARALYSIS

If passive movements of the wrist and fingers are unrestricted, tendon transplantation may be utilized to restore, to some extent, digital flexion; though flexion may be restored to a certain degree through transplantation of extensors, the loss of the intrinsic hand muscles greatly limits the usefulness of the hand beyond the ability to hold or carry objects.

Technique

a. Splitting the tendon of the extensor carpi radialis longior, one slip of which is transplanted into the sublimis and profundus tendons of the index finger, a second slip is transplanted into the same tendons of the ring finger—through a long incision, extending from the base of the thumb to the upper third of the dorsum of the forearm, the long ribbonlike tendon of the extensor carpi radialis longior is identified between the extensor brevis, to its ulnar side; and the brachioradialis, to the radial side. At the wrist, these tendons are crossed by the bellies of the extensor ossis metacarpi pollicis, extensor brevis pollicis, and the tendon of the long flexor of the thumb. The tendon of the long radial extensor is divided at its insertion into the second metacarpus. Its sheath is opened high up and the tendon withdrawn and split. The tendon of the brachioradialis is now identified and divided, and its borders freed from fascial attachments some distance up the forearm; in mobilizing the brachioradialis caution should be used in the isolation of the radial nerve and artery, which lie on its under surface. Several muscular branches of the radial artery will require ligation.

b. Transplantation of the brachioradialis tendon into both flexor tendons of the ring and little fingers—a ventral incision is now made, extending from the base of the thumb, near the insertion of the flexor carpi radialis tendon, along the radial border of the flexor surface of the forearm to the junction of its upper

and middle thirds. The skin and fat of the superficial fascia is undermined between the two incisions, permitting the passage of the extensor and brachioradialis tendons to the ventral aspect of the forearm in a straight course. Medial retraction of the ventral incision permits exposure of the long flexor tendons, each of which should be identified and arranged in pairs, sublimis and profundus for each finger. The long flexor of the thumb is identified and separately isolated. With the fingers completely flexed, the lateral slip of the divided long extensor tendon is passed through a slit in the sublimis and profundus flexors of the index finger; the medial half of the radial extensor tendon is anastomosed into both flexor tendons of the ring finger. The tendon of the brachioradialis is now brought forward in as direct a line as possible and inserted in a like manner into the flexor tendons of the ring and little fingers.

c. Transplanting extensor ossis metacarpi pollicis into the flexor longus pollicis—the extensor ossis metacarpi pollicis tendon is divided at its insertion and transplanted into the long flexor of the thumb, with the thumb flexed over the previously flexed fingers, making a fist. After the proper tension has been placed on these transplanted tendons, so that the fingers are flexed equally, and with the wrist in partial flexion, the tendons are anchored.

Both dorsal and ventral skin incisions are now closed while the hand is maintained in complete digital and partial wrist flexion. This position is maintained by suitable pads and bandages, after a small unrolled bandage is placed in the hand. (After-treatment and reeducation are conducted along the usual lines.)

THE SCIATIC TRUNK AND ITS TERMINAL DIVISIONS

GENERAL ANATOMY

The sciatic trunk is formed by the ventral and dorsal divisions of the fourth and fifth lumbar, and second and third sacral nerves. The ventral divisions go to make up the medial or tibial portion of the sciatic trunk, while the dorsal form its lateral or peroneal portion.

The tibial and peroneal portions of the sciatic trunk are from a physiologic standpoint totally differentiated, though anatomically they are usually incorporated into a single nerve trunk for some distance down the thigh. The extent of their union, however, varies, and occasionally the sciatic trunk is replaced by two distinct nerves, emerging from the great sacrosciatic foramen. More often, however, their union continues to the upper part of the popliteal space, where the sciatic trunk divides into its terminal divisions; the medial or tibial portion becoming the internal popliteal nerve, while its lateral or peroneal forms the external popliteal nerve. The separation in the thigh of the component tibial and peroneal portions of the sciatic trunk is always more or less evident, varying from a complete separation, in which each nerve has a distinct and separate sheath, to the type in which inspection alone fails to demonstrate the anatomical division and in which palpation is required to give the surgeon a clue as to the line of cleavage. These nerves, when combined in a single sheath, are anatomically separated by a septal prolongation of the sheath, which is usually evident on cross section. As the trunk proceeds down the thigh, the demarcation between its component parts becomes more conspicuous on its surface, and its dividing septal sheath shows greater development.

Though the tibial portion of the sciatic trunk is usually described as lying medial, and the peroneal portion lateral, the line of division does not strictly follow a ventrodorsal plane; the tibial portion lies somewhat more ventral than dorsal, while the peroneal portion occupies a dorsolateral position.

After emerging from the pelvis to the dorsum of the thigh, through the great sacrosciatic foramen under the pyriformis muscle, the sciatic trunk passes down the posterior aspect of the thigh to the popliteal space. In its upper part it lies on the external rotators of the thigh, and below these upon the dorsal surface of the adductor magnus. In its gluteal portion, the nerve is covered by the gluteus maximus; in the thigh it runs parallel with and to the lateral side of the flattened tendon of the semimembranosus, and is crossed and covered in most of this portion by the thick belly of the ischial head of the biceps.

NERVE TO HAMSTRING MUSCLES

The nerve to the hamstring muscles, while commonly incorporated within the sheath of the tibial portion of the sciatic trunk, should not be regarded as a collateral branch of the tibial nerve, but rather as one of the three separate elements, which, being bound together by a common sheath, constitute the great sciatic trunk, namely, from within outward, nerve to the hamstrings, tibial nerve, and peroneal nerve. The nerve to the hamstrings may or may not be incorporated within the sheath of the sciatic trunk, but always lies to the medial side of the tibial portion of the sciatic; when incorporated within its sheath it is usually anatomically separated by a well-developed sheath of its own and may be readily separated from the sciatic trunk. The short or humeral head of the biceps, however, is supplied about the middle of the thigh by a branch which leaves the lateral surface of the peroneal portion of the sciatic. This branch has a distinct intraneural course and may or may not be regarded as a collateral branch of the peroneal nerve. The nerve to the hamstrings supplies the semitendinosus, semimembranosus, long head of the biceps, and a portion of the adductor magnus.

TERMINAL BRANCHES

The tibial nerve (internal popliteal), which formerly occupied a ventromedial position, upon leaving the sciatic trunk in the lower third of the thigh, enters the popliteal space, where it lies in a pad of fat, superficial to the popliteal vessels. It passes longitudinally through the middle of the popliteal space, from which it emerges by passing ventral to the union of the two heads of the gastrocnemius. It terminates at the lower border of the popliteus muscle, by passing through an arch in the soleus muscle, accompanied by the popliteal artery and vein, where it becomes the posterior tibial nerve.

In the popliteal space, motor branches arise to supply the gastrocnemius, plantaris, soleus, and popliteus muscles; these branches are given off from the dorsal surface of the nerve. At the upper part of the popliteal space, a large branch diverges from each side of the nerve trunk to the two heads of the gastrocnemius. Though usually given off as separate branches, their intraneural origin is from a bundle common to all of the above-mentioned muscles; it has a rather long intraneural course, lying on the dorsal aspect of this portion

of the sciatic trunk. Occasionally, the nerve to the soleus leaves the parent trunk in common with the branch to the lateral head of the gastrocnemius. The branches to the plantaris and popliteus are usually given off individually, but their intraneural course is common with the gastrocnemius and soleus fibers. Below the branches to the gastrocnemius, a sensory branch is given off, the communicans tibialis, which passes downward in the sulcus between the two heads of the gastrocnemius, becoming superficial in the calf by piercing the deep fascia where it joins the peroneal communicating to form the external or short saphenous nerve, which supplies sensation to the lower third of the leg on its outer side, and the outer side of the foot and little toe. The tibial nerve also gives off branches to the knee joint and to the posterior tibial vessels.

The posterior tibial nerve, the terminal portion in the leg of the tibial (internal popliteal) nerve, passes down the leg, occupying a deep position between the deep and superficial muscles of the calf, in a special compartment in the intermuscular septum between these muscles, accompanied by the posterior tibial artery and its venæ comites, in relation to which it holds a superficial or dorsal position. In the lower part of the leg, it lies medial and ventral to the tendo Achillis; after passing behind the internal malleolus it enters the sole of the foot, to terminate as the internal and external plantar nerves. Immediately after the posterior tibial nerve is formed by passing through the arch of the soleus muscle, it breaks up into a number of branches which supply the lower portion of the soleus, the tibialis posticus, the flexor longus digitorum and the flexor longus hallucis.

The peroneal nerve (external popliteal), considerably smaller than the tibial nerve, after leaving the common sciatic trunk, at the apex of the popliteal space, follows the lateral border of the fossa and the medial margin of the biceps tendon. Passing over the plantaris and lateral head of the gastrocnemius, it winds around the neck of the fibula, where it enters a canal in the origin of the peroneus longus muscle, and breaks up into its terminal branches.

In the popliteal space, the peroneal nerve gives off the following collateral sensory branches, from the dorsal portion of its trunk: *The communicating peroneal* which passes medially across the lateral head of the gastrocnemius, pierces the deep fascia on the back part of the leg and unites with the communicating tibial to form the short or external saphenous nerve; *the sural branches*, which may arise in common with the communicating peroneal or at a lower origin to supply the skin over the back and outer side of the calf and leg. Intraneurally, the fibers forming these nerves originate from a single bundle which occupies a long intraneural course on the dorsal surface of the peroneal portion of the sciatic trunk.

The terminal branches of the peroneal nerve are given off after it swings around the neck of the fibula and passes through a canal in the peroneus longus muscle. They are the musculocutaneous, anterior tibial, and tibial recurrent. The anterior tibial branch springs from the lower portion of the flattened peroneal trunk and has a long intraneural course, composed of a single bundle which in the upper part of the popliteal fossa lies in the ventral portion of the nerve. The musculocutaneous branch arises from the ventral portion of the trunk and likewise has a long, intraneural course, though composed of two bundles, one

of which contains motor fibers to the peronei muscles, the other containing the sensory fibers.

The musculocutaneous nerve, lying at first between the peroneus longus muscle and fibula, passes obliquely downward and forward; it is deeply placed and located in a fibrous canal in the septum between the peronei and extensor longus digitorum; it supplies the peroneus longus and brevis with motor branches. In the middle of the leg it penetrates the deep fascia and divides into an internal and external branch, supplying the skin of the front of the leg and dorsum of the foot and toes.

The anterior tibial nerve, originating from the peroneal between the recurrent tibial and musculocutaneous, passes downward and forward beneath the extensor longus digitorum to the ventral surface of the interosseus membrane, where it passes down the leg accompanied by the anterior tibial artery and its venæ comites, lying between the tibialis anticus and the extensor longus hallucis. At the ankle it is crossed by the tendon of the extensor longus hallucis, as it passes to the dorsum of the foot, where it divides into its external and internal terminal branches. The anterior tibial nerve supplies motor fibers to the tibialis anticus, extensor longus hallucis, extensor longus digitorum and peroneus tertius. Its external branch supplies the extensor brevis digitorum, and its internal branch the integument between the first and second toe and a small area on the dorsum of the foot adjacent to these toes.

The tibial recurrent nerve, the smallest, most anterior and highest of the three terminal branches of the tibial nerve, passes between the origin of the peroneus longus and the fibula, giving motor branches to the upper portion of the tibialis anticus and articular branches to the knee joint.

SURGERY OF THE SCIATIC TRUNK

In war surgery injuries of the sciatic trunk are far more common than any other nerve lesion in the lower extremity. While severance of the entire trunk does occasionally occur, this incident is rare. The nerve to the hamstrings seldom shows complete paralysis, and very frequently the peroneal portion of the sciatic trunk alone suffers injury. This is probably due to the position of the peroneal in the sciatic trunk, where it occupies a dorsolateral position and tends to protect the tibial portion of the nerve. The components of the sciatic trunk may suffer injury in any part of their course in the buttocks, thigh, popliteal space, or leg. Throughout its entire course the tibial nerve is afforded greater protection than the peroneal. The peroneal is particularly liable to injury in the region of the head of the fibula, where it occupies a very superficial position.

The surgery of the sciatic trunk resolves itself into the surgery of its component elements, and not infrequently exposure will reveal the entire trunk extensively involved in scar tissue when clinically the lesion is confined only to its peroneal portion. The surgeon must therefore be governed by clinical indications rather than by the gross pathologic appearance of the nerve at operation, and thereby avoid the sacrifice of intact sciatic elements. Surgery of the sciatic trunk resolves itself into the exposure of three regions, namely: For gluteal lesions, upper thigh lesions, and lower thigh lesions. In

the gluteal region the nerve is exposed by reflecting the gluteus maximus; in the upper thigh, by retracting the ischial head of the biceps medially; while in lower thigh lesions this muscle is retracted laterally. It is essential therefore that the surgeon be familiar with the technique involved in exposing the sciatic trunk in these regions; in addition to this, he must be able to appreciate and differentiate the component parts of the trunk, and, in suture, to effect perfect matching and alignment of its respective elements. The approximation of the peroneal to the tibial portion through torsion of the trunk would obviously be a catastrophe, and though neuraxon regeneration might progress unimpeded, the disturbance of physiologic pattern would give very confusing and unsatisfactory results. The sciatic trunk must be considered not as an individual nerve but as three distinct elements closely approximated in a common sheath, namely, from within outward, the nerve to the hamstrings, the tibial, and the peroneal. The nerve to the hamstrings seldom requires surgical intervention, while the two remaining elements, the tibial and peroneal portions, are commonly involved, though the two latter are so separated by a septal prolongation of the sciatic sheath that identification is rendered possible and perfect alignment facilitated by observing and maintaining the position of this septum in suture. In this respect, the sciatic trunk offers in the majority of cases a most satisfactory means of effecting physiologic approximation.

EXPOSURE IN GLUTEAL REGION

Exposure of the sciatic trunk in the gluteal region is most satisfactorily accomplished and less trauma inflicted by dividing the tendon of the gluteus maximus at its insertion into the femur and reflecting it medially. This exposure not only assists in preserving the nerve supply to the gluteus maximus, but also is effective in avoiding the troublesome hemorrhage associated with a cross section of its fibers. The line of incision is curved, with its base outward, and extends from the posterior iliac spine outward and downward to the upper border of the great trochanter of the femur, and, slightly posterior, it passes downward over the insertion of the gluteus maximus tendon; it then curves backward, following the gluteal fold to the midline of the thigh, down which it may be extended over the course of the sciatic nerve, as far as the individual exposure necessitates. The deep fascia is exposed and divided in the line of incision. Along the upper border of the incision the fibers of the gluteus maximus are split in their line of cleavage and the tendon exposed and divided close to its insertion in the femur, permitting a medial reflection of the lower half of this muscle. In reflecting the gluteus maximus, care should be used to prevent injury to branches of the inferior gluteal vessels. To avoid obscuring the field, these vessels, when possible, should be caught and divided between forceps. The sciatic trunk is now exposed as it emerges from the great sacrosciatic foramen below the pyriformis muscle, and again care must be used to prevent injury to the inferior gluteal nerve which emerges from under the pyriformis along the dorsal surface of the sciatic trunk, accompanied by branches of the inferior gluteal artery and veins. To the medial side of the great sciatic trunk lies the small sciatic nerve, which may be differentiated from the nerve to the hamstrings by following its course to the lower border

of the gluteus maximus, where it becomes superficial. The nerve to the hamstrings in this region may be either incorporated within the sheath of the sciatic trunk or it may pass along its medial side as a separate nerve. Electrical stimulation will readily serve to identify this motor branch when doubt exists. In this region the sciatic trunk is surrounded by many vascular branches, necessitating great caution; the reckless or blind application of a hemostat in this region to control an unseen bleeder may result in injury to important motor branches. The sciatic trunk may be followed beneath the pyriformis muscle, and for a short distance within the foramen, by upward retraction of the pyriformis. Even better exposure may be had by dividing its tendon and reflecting the muscle medially. After all vessels have been carefully ligated to avoid, as much as possible, the subsequent oozing, the tendon of the gluteus maximus is sutured with strong linen. Drainage should always be instituted for a period of 48 hours to care for oozing, which is usually abundant following this exposure.

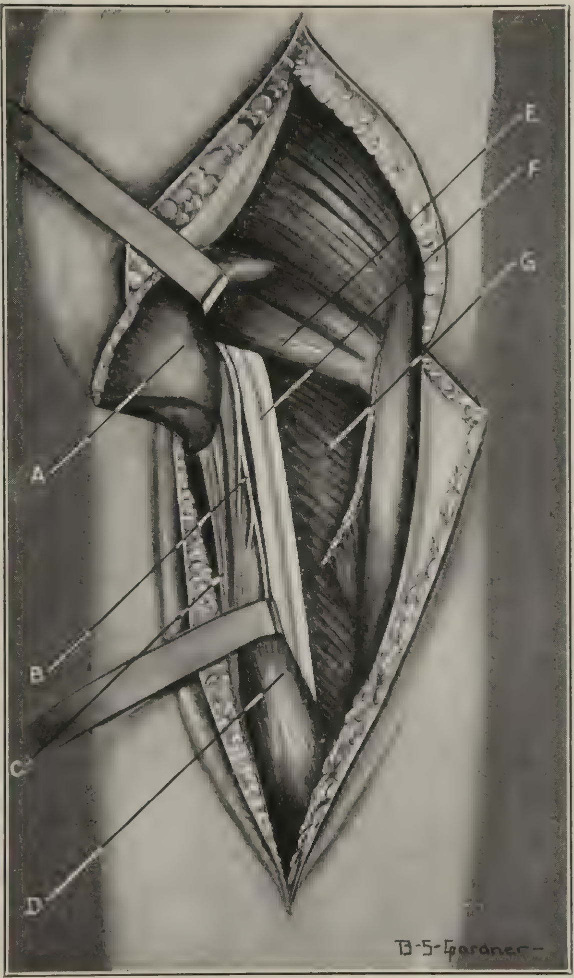

FIG. 192.—Exposure of sciatic trunk and branches to the hamstrings in gluteal region; insertion of gluteus maximus divided and this muscle reflected, exposing the sciatic nerve emerging from the greater sacro-sciatic foramen below the pyriformis muscle. A, Gluteus maximus, lower portion reflected; B, nerve to hamstrings; C, semitendinosus tendon; D, biceps, long head; E, pyriformis; F, sciatic trunk; G, adductor magnus

EXPOSURE IN THE THIGH

As the sciatic trunk emerges from below the lower border of the gluteus maximus, it passes down the middle of the dorsum of the thigh, resting upon the adductor magnus, in close proximity to the ribbon-like tendon of the semimembranosus. The nerve trunk is fairly superficial at the lower border of the gluteus maximus and at the popliteal space, where it is covered only by an abundance of surrounding fat and the deep fascia. In the middle of the thigh, however, the sciatic trunk is diagonally crossed by the ischial head of the biceps from within outward, the nerve being deeply placed beneath the fleshy belly of this muscle.

Exposure of the sciatic trunk in the thigh is accomplished through a mid-dorsal longitudinal incision, extending from a few centimeters above the gluteal fold to the popliteal space. The small sciatic nerve lies in close relation to the deep fascia in this region and should be identified and preserved if possible. While it is purely sensory and not of great importance, its identification and retraction will serve to prevent irritative symptoms, following the accidental strangulation by suture, during closure of the deep fascia. If the lesion be an upper thigh lesion, the lateral border of the ischial head of the biceps is identified and retracted medially, exposing the flattened tendon of the semimembranosus, which must not be mistaken for the sciatic trunk, lying immediately along its lateral border, surrounded by an abundance of fat. The lower border of the gluteus maximus is undermined and retracted upward to afford higher exposure and if necessary a few of its fibers may be divided. In lower thigh lesions, the medial border of the ischial head of the biceps is identified and retracted laterally, exposing the nerve below. Medial or lateral retraction of the ischial head of the biceps will usually permit a satisfactory exposure of the sciatic trunk in any part of its course below the gluteus maximus. After identifying the nerve trunk, attention must be given to its component parts. The nerves to the hamstrings, passing along its medial border, must be identified and carefully retracted medially to prevent their injury during dissection of the trunk. The sciatic trunk in the thigh may present itself as a single large nerve, or the division of its component tibial and peroneal portions may be conspicuous by their complete separation, or by markings on the sheath of the trunk along their line of cleavage. If inspection of the trunk fails to reveal

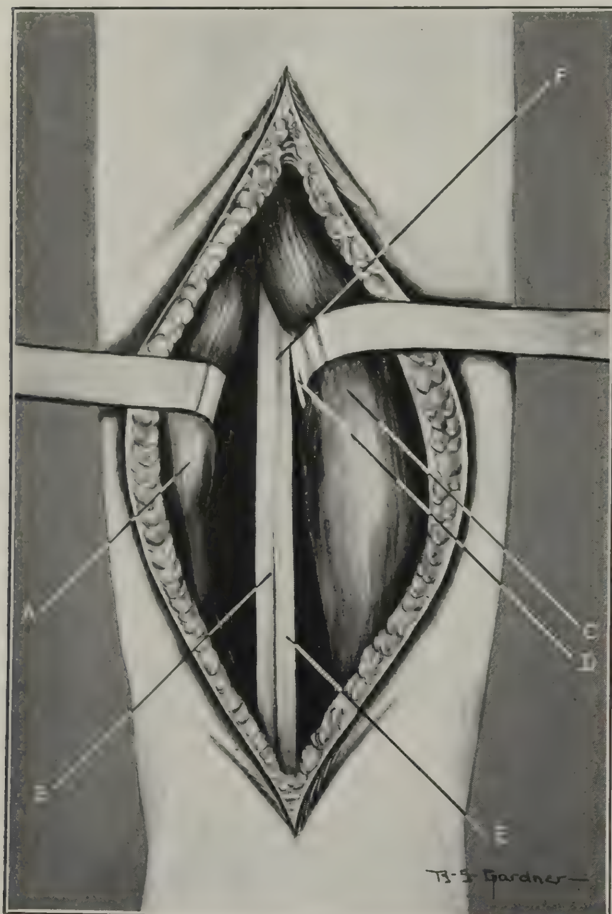

FIG. 193.—Exposure of the sciatic in the middle and lower thirds of the thigh by lateral retraction of the short head of the biceps. Branches to the short head of biceps is shown emerging from the lateral side of the peroneal division of the sciatic trunk about the middle of the thigh. A, Semimembranosus; B, tibial nerve; C, biceps, long head; D, branch to biceps, short head; E, peroneal nerve; F, sciatic trunk

any line of demarcation between its respective tibial and peroneal portions, palpation, or rolling the nerve between the fingers, will usually serve in effecting this identification. It should be remembered that the component portions of the sciatic trunk are separated by a more or less well-defined septal prolongation of its sheath; that its tibial elements occupy a medial position, somewhat more ventral than dorsal; that the peroneal portion, which is the smaller of the

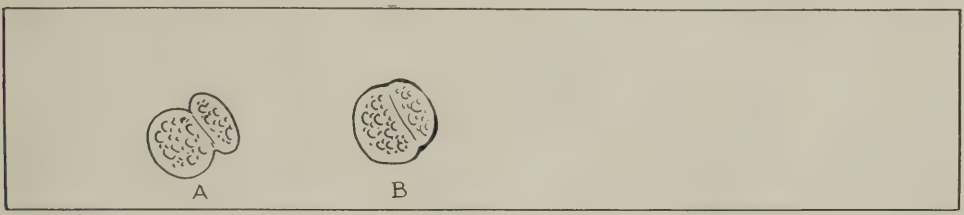

FIG. 194.—Diagrammatic cross section of sciatic trunk, showing its tibial and peroneal components. The septal division between these portions of the sciatic trunk does not lie in a strictly ventro-dorsal plane. The peroneal or smaller division of the trunk occupies a ventro-medial position. A, A type of sciatic nerve trunk in which the line of division between its component parts is evident by a groove on the surface of the nerve. B, Type in which separation of the component parts is not so evident. (The above diagram represents the right sciatic trunk as exposed through a dorsal incision; the upper part of the diagram represents the dorsal surface of the sciatic trunk)

two, is located in the dorsolateral aspect of the trunk. The line of cleavage, therefore, will not be found in a strictly ventrodorsal plane, but passing from the center of its dorsomedial quadrant to its ventrolateral quadrant. Rotation of the sciatic trunk outward will serve to rotate the plane of the intraneural septum to a ventrodorsal position. Occasionally, it will be necessary to find the line of cleavage between the peroneal and tibial portions at their division in the popliteal space, from which point they may be carefully separated up

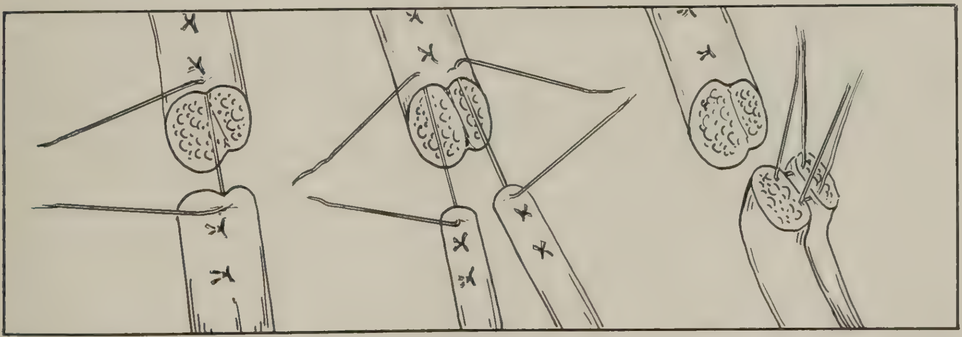

FIG. 195.—Method of alignment in physiologic approximation of the sciatic trunk, the intraneural septum between the peroneal and tibial portions of the trunk serving as a guide to alignment

the sciatic trunk. In effecting such a separation, the septal division should be closely followed. There is no intercommunication of fibers between the component elements of the sciatic trunk, and this separation may be accomplished, if executed with sufficient care, without destruction to nerve elements. The septum dividing the sciatic trunk into its component portions serves admirably as a guide in effecting physiologic alignment during suture. Identification sutures in the sheath of the nerve should be placed in a position to assure per-

fect alignment of the intraneural septum, and if it becomes necessary to disturb the relationship between one portion of the trunk and this septum, surface markings should be so placed that identification of this region is assured before the original relationship has been disturbed.

EXPOSURE OF THE TIBIAL NERVE (INTERNAL POPLITEAL) IN THE POPLITEAL SPACE

The skin incision extends longitudinally through the middle of the popliteal space, from a few centimeters above its apex to a point a few centimeters below the union of the two heads of the gastrocnemius. The deep fascia is divided, exposing the fat of the popliteal fossa. The tibial nerve should be identified as it emerges at the upper part of the fossa from below the medial border of the biceps; its distal portion is identified as it passes below the union of the two heads of the gastrocnemius. Having located the nerve at these two points, it may be followed through the popliteal space by dividing the overlying fatty tissue. Several vascular branches will be met and divided between clamps to prevent obscuring the field. A careful exposure in this way will usually avoid injury to the popliteal vessels. The small saphenous vein joins the popliteal vein about the middle of the fossa and will require ligation. Near the apex of the popliteal space the tibial nerve gives off diverging motor branches to the two heads of the gastrocnemius. These branches originate from a common bundle on the dorsal surface of the nerve, which by intraneural dissection may be followed some distance up this portion of the sciatic trunk.

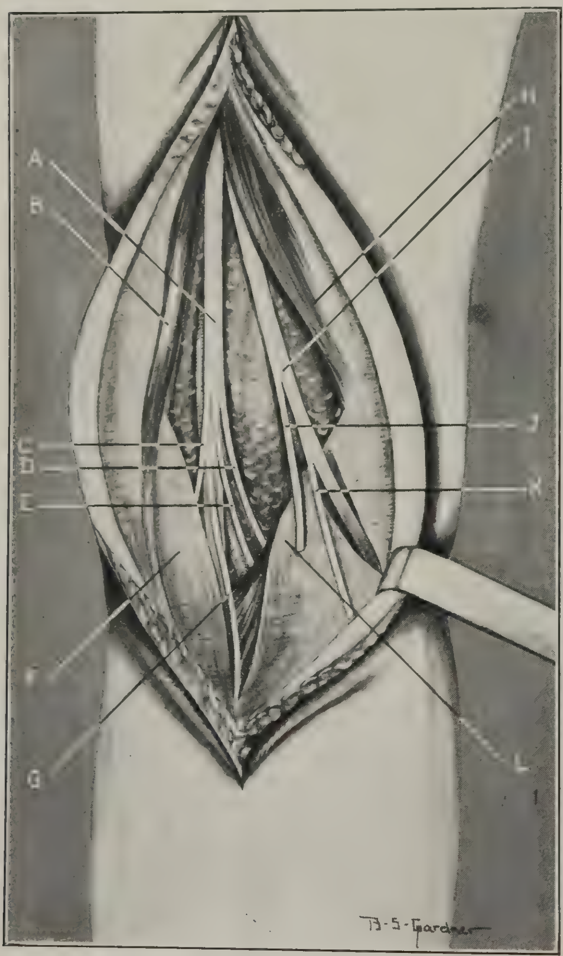

FIG. 196.—Exposure of the external and internal popliteal nerves in the popliteal space. A, Tibial nerve; B, internal hamstring tendon; C, branch to gastrocnemius, medial head; D, branch to gastrocnemius, lateral head; E, branch to soleus; F, gastrocnemius, medial head; G, tibial communicating nerve; H, lateral hamstring tendon; I, peroneal nerve; J, peroneal communicating; K, sural nerve; L, gastrocnemius, lateral head

These branches by their intraneural localization identify the dorsal surface of the tibial nerve. Occasionally, one of the branches of the gastrocnemius will

carry fibers to the superficial fibers of the soleus; at other times the branch to the soleus is given off from the tibial trunk at a lower level. Intraneural dissection reveals this branch, however, it may reach the soleus, as springing from the common gastrocnemius bundle. A small branch to the plantaris may be given off directly from the tibial trunk or from the branch to the lateral head of the gastrocnemius. After the nerve has passed below the gastrocnemius, a small branch is given to the popliteus muscle. Shortly after the divergence of the motor nerves to the two heads of the gastrocnemius, a sensory branch, the communicating tibial, leaves the tibial trunk and passes in the sulcus between the two heads of the gastrocnemius to pierce the deep fascia and enter into the formation of the external saphenous. Branch identification in the popliteal space should at least include the branches to the gastrocnemius and soleus, and the tibial communicating. The identification of each is simplified by its course, the nerves to the gastrocnemius diverging respectively to its medial and lateral heads; the communicating tibial by its superficial course. If access to the tibial nerve is desired below the popliteal fossa, the line of cleavage between the two heads of the gastrocnemius may be split as far down this muscle as necessary without disturbing its nerve supply. With the retraction of the lateral and medial head of the gastrocnemius, the tibial nerve may be readily followed to the point where it disappears under the tendinous arch of the soleus, accompanied by the popliteal vessels.

SURGERY OF THE POSTERIOR TIBIAL NERVE

A certain number of lesions of the posterior tibial nerve are overlooked, because patients frequently ignore the intrinsic paralysis and anesthesia of the sole of the foot. There are, however, certain lesions which are associated with marked irritative symptoms referred to the sole of the foot, and these, in many instances, are peculiarly resistant to the moderating effect of time and sedative treatment, and occasionally require neurolysis, alcohol injection, or even excision of the posterior tibial nerve. The writer has observed one instance in which the painful syndrome in the sole of the foot persisted after a neurolysis of the posterior tibial nerve and a subsequent alcohol injection, and was later relieved by a decortication of the popliteal artery. In the lower part of the popliteal space several branches pass from the tibial trunk to the popliteal vessels; these branches follow the vessels through the canal in the soleus and are probably active to some degree in the production of irritative phenomena. In effecting a decortication of the popliteal artery the denudation should proceed to the opening in the soleus muscle by splitting and retracting the heads of the gastrocnemius.

As the tibial nerve passes through the tendinous arch of the soleus to become the posterior tibial, it divides into two branches, the dorsal of which immediately breaks up into a number of branches to supply the ventral surface of the soleus, tibialis posticus, flexor longus digitorum, and flexor longus hallucis. The other branch of the nerve passes down the leg in a compartment formed by the intermuscular septum, separating the superficial from the deep calf muscles, accompanied by the posterior tibial artery and its venæ comites. In the lower third of the calf it is more superficial, lying to the medial side of

the tendo Achillis and covered by the deep fascia. In this region the nerve is composed of two bundles, which ultimately go to the formation of its terminal internal and external plantar branches.

Exposure of the posterior tibial nerve in its deep position in the upper two-thirds of the calf is best accomplished through a mid-dorsal incision, extending from the middle of the popliteal space to the lower third of the leg, where it curves somewhat to the medial border of the tendo Achillis. In exposing the deep fascia care should be used to avoid injury to the tibial communicating branch of the tibial nerve, which unites in the middle of the calf with the peroneal communicating branch to form the external saphenous nerve. Injury to this branch, which is sensory in function, is productive of but little disturbance, but when a lesion is already associated with a certain amount of anesthesia it is not wise to easily sacrifice other sensory branches. Identification and isolation of this nerve is also important, in that with closure of the deep fascia it may be caught in the sutures, resulting in considerable pain and possible irritative phenomena. The short saphenous vein is also encountered and should be ligated to prevent tearing and troublesome hemorrhage. The incision is now carried through the deep fascia, and the gastrocnemius bisected, from the point of union between its two heads to the tendo Achillis and widely retracted, exposing the soleus muscle below. The soleus muscle is now bisected in the same way, exposing the intermuscular septum below. It will be remembered in splitting the soleus muscle that it has an aponeurosis covering its dorsal surface, which must not be mistaken for the underlying intermuscular septum. Both gastrocnemius and soleus, now having been longitudinally bisected from their origin to the tendo, Achillis are retracted, exposing the deeply placed intermuscular septum, separating the superficial muscles from the deep. The posterior tibial nerve and its accompanying artery and veins will be found by splitting the fascia along the medial border of the flexor longus hallucis muscle. The close proximity of the posterior tibial nerve to its accompanying arterial structures renders its dissection rather tedious, because of the frequent tearing of veins. The simplest procedure to follow is: Ligation or clamping of veins in the lowest part of its course; in the upper part, compression of the posterior tibial artery, thus greatly facilitating isolation of the nerve.

In the lower third of the leg the tibial nerve may be located along the medial border of the tendo Achillis by dividing the deep fascia, extending from the tendo Achilles to the deep muscles. The nerve will be found lying between the flexor longus digitorum and the flexor longus hallucis.

EXPOSURE OF THE PERONEAL NERVE (EXTERNAL POPLITEAL) IN THE POPLITEAL SPACE

The incision extends from the apex of the popliteal fossa, following the medial border of the external hamstring tendon; it passes around the neck of the fibula, and, for a short distance down the anterolateral surface of the leg, midway between the crest of the tibia and fibula. The deep fascia is divided in the line of the incision; as it approaches the head of the fibula, this fascia

will be found to be greatly thickened and great care should be used in its division to prevent injury to the nerve, which lies immediately under its deep surface and to which it may be adherent. The nerve should first be located at the apex of the popliteal fossa, where it leaves the sciatic trunk, and followed along the border of the biceps tendon. As it crosses the plantaris and the lateral head of the gastrocnemius the peroneal nerve becomes greatly flattened, which shape it retains in its passage around the neck of the fibula under cover of the peroneus longus, where it breaks up into its terminal divisions.

In the popliteal fossa the peroneal nerve gives off sensory branches. The peroneal communicating is the superior branch and crosses the head of the gastrocnemius muscle toward the posterior aspect of the calf, where it perforates the deep fascia and joins with the tibial communicating to form the external saphenous nerve. A short distance below the peroneal communicating the sural branch or branches are given off, supplying sensation to the external surface of the leg. Occasionally the sural branches leave the tibial trunk with the peroneal communicating. These sensory branches spring from the dorsal aspect of the tibial trunk and have a long combined intraneural course.

FIG. 197.—Exposure of external popliteal and its terminal divisions as it swings around the neck of the fibula, the insertion of the peroneus longus having been divided to expose the terminal branches. A, Lateral hamstring tendon; B, head of fibula; C, origin of peroneus, divided; D, peroneal nerve; E, peroneal communicating; F, sural nerve; G, peroneal nerve; H, anterior tibial nerve; I, tibial recurrent; J, musculocutaneous nerve; K, branches to peronei; L, musculocutaneous, sensory portion

In the upper part of the popliteal fossa the peroneal nerve is composed of four bundles, the most dorsal of which contains the sensory fibers of the peroneal communicating and sural nerves. Below this sensory bundle, two bundles are found, one of which contains motor fibers to the peronei muscles, the other containing sensory fibers to the musculocutaneous nerve. Below these, in the ventral part of the nerve trunk, lies a bundle which contains fibers for the anterior tibial nerve. As the nerve proceeds along the lateral border of the popliteal fossa and the dorsal cutaneous bundle is given off in the formation of

the peroneal communicating and sural nerves, it undergoes a degree of torsion and flattening in passing over the lateral head of the gastrocnemius, so that the three remaining bundles lie side by side in a mediolateral plane; the most medial bundle now being that which ultimately forms the anterior tibial nerve, the two lateral bundles, soon to unite, form the musculocutaneous nerve—the more lateral bundle containing the motor fibers to the peroneal muscles, the medial bundle, the sensory fibers to the musculocutaneous. As the flattened trunk passes around the head of the fibula, the lateral bundle forms the musculocutaneous nerve and the dorsal, or lower, bundle forms the anterior tibial and tibial recurrent nerves.

Exposure of the terminal branches is accomplished by carefully dividing the fibers of the peroneus longus at its origin, as the nerve is followed around the bone. Occasionally it is possible to effect suture of the individual branches as in the posterior interosseous nerve, where it fans out; beyond this point, reconstruction becomes increasingly difficult.

Physiologic approximation of the peroneal nerve is greatly facilitated by the position of its branches and the flattened or ribbonlike shape of the nerve in the lower part of the fossa and as it passes around the neck of the fibula. In the upper part of the popliteal fossa, the dorsal surface of the nerve is definitely indicated by the position of its sensory branches. In this position the nerve is oval in shape, its longest axis being in a ventro-dorsal plane. As it passes over the lateral head of the gastrocnemius, the dorsal quadrant of the nerve is rotated to a lateral position, which in passing around the neck of the fibula becomes ventral and superior, and from this ventral border the musculocutaneous nerve is given off. The dorsal part of the nerve, which is now inferior, becomes the anterior tibial, which gives off the tibial recurrent nerve. Though most writers describe the tibial recurrent nerve as one of the terminal peroneal branches, its intraneural course is common with the bundle containing anterior tibial fibers. With a visualization of the natural torsion occurring in the peroneal trunk in the popliteal fossa and as it winds around the neck of the fibula, and with the assistance afforded by the flattened shape of the nerve trunk, the surgeon should have little difficulty in effecting physiologic approximation.

CONTINUITY DEFECTS

Relatively large defects in the sciatic trunk and its terminal external and internal popliteal portions may be overcome by flexion relaxation of the knee, providing these nerves are extensively mobilized, particularly in the popliteal fossa. There is no type of transposition which can be used in the lower extremity to shorten the course of these nerves. Defects, therefore, uncorrected by primary stretching and flexion relaxation, if at all correctable, will probably yield only to secondary stretching, i. e., the two-stage operation, in which the unsectioned nerve ends are united, after full advantage is taken of primary stretching and flexion relaxation, by extensive liberation of the nerve trunk in both directions. In the writer's experience, several cases were encountered in which approximation seemed hopeless at the primary operation, and grafting was resorted to. In each instance regeneration failed, but in a subsequent

operation end-to-end suture was effected by the two-stage method. We believe that the two-stage operation will probably be found efficacious in approximating any correctable defect, and that grafts should be resorted to only after the two-stage operation has failed, certainly never before it has been attempted. When end-to-end approximation has been despaired of, and in cases of incorrectable regenerative failure, the disability, in so far as ankle instability and drop-foot are concerned, may be fairly well corrected by arthrodesis or tendon transplantation. (See irreparable defects, p. 959.)

SECONDARY SUTURE

Defective regeneration in sciatic lesions, as in other nerves, may be due either to defective neuraxon, or defective muscle regeneration: it is of utmost importance, in considering the question of secondary operation, to determine the degree of responsibility of each. In approximately 85 per cent of complete sciatic trunk sutures, plantar flexion of the foot returns to some degree through regeneration in the gastrocnemius-soleus group. In about 40 per cent of cases, some voluntary power, after a four-year period, is observed in the peroneus longus and tibialis posticus. In about 30 per cent, some flexion of the toes is observed, while return of voluntary movement in the tibialis anticus and extensor of the toes is found in less than 20 per cent. In no case has the writer observed a regeneration of the intrinsic foot muscles, following sciatic suture or suture of one of its terminal branches. In approximately 80 per cent of suture cases there has been return of sensation, to some degree, in the foot, though rarely, after four years, has the writer observed a complete disappearance of anesthesia, though in most instances trophic disturbances and pressure sores have ultimately healed. In the majority of instances in which anesthesia has disappeared, discriminative sensation has not been recovered, the anesthetic zone having been replaced by a type of nondiscriminatory sensation, which is usually interpreted by the patient as tingling; there seems, however, to be a tendency toward a gradual sensory improvement. A few of these patients find it possible to distinguish between hot and cold water when taking a bath, but are unable to localize touch, or discriminate between a dull and sharp point. A study of these regenerative defects throws important light upon both muscle and nerve regeneration.

Neuraxon regeneration is demonstrated by Tinel's sign and in most instances is found to be present in some degree. When Tinel's sign is totally absent below the suture line, or is greatly diminished in intensity, after six months, a defective suture is probably accountable. This is particularly true when pressure over the suture line elicits a strong reaction; in such instances secondary suture is indicated.

In a number of cases, percussion of the peroneal nerve over the head of the fibula has elicited tingling, localized on the plantar surface of the foot. This indicates that the tibial portion of the nerve during suture was probably united to the peroneal, in that tibial sensory fibers are present in the peroneal trunk. In other instances, the writer has observed plantar flexion of the foot when the patient was attempting dorsoflexion, which was perhaps due to the

presence of peroneal motor fibers having reached the gastrocnemius. The presence of some regeneration in the gastrocnemius in about 80 per cent of cases can be accounted for in two ways: First, this muscle, because of its large size and high innervation, receives a certain number of regenerated motor fibers; second, because of the drop-foot, it is seldom overstretched as are the extensors of the anterolateral group. The failure of recovery in the tibialis posticus and flexors of the toes indicates that overstretching is not entirely responsible for these motor defects, which in all probability are due to an extreme degree of muscular degeneration and atrophy following prolonged denervation. The failure of muscle regeneration in the intrinsic foot muscles can probably be accounted for by extreme muscular degenerative changes, due to their small volume and distal position. We have not observed a single instance of regeneration in the intrinsic foot muscles, following a paralysis lasting longer than 18 months. Even in cases of spontaneous regeneration, or after a neurolysis, with probably no disturbance of nerve pattern and in which sensation was fully recovered, the intrinsic foot muscles failed to show any signs of regeneration and their extreme atrophy persisted.

The frequent failure of regeneration in the extensors of the anterolateral group, namely, tibialis anticus, extensor longus hallucis, and extensor longus digitorum, requires special comment. A number of cases have been observed, following suture and neurolysis of the peroneal nerve, in which the anesthetic areas showed much improvement, without a restoration of motor function in these muscles, while voluntary power was observed to have returned in the peroneus longus. Instances of this kind can be explained only on the ground of muscle stretching due to foot-drop, which the peroneus longus escapes, by the anatomical course of its tendon behind the external malleolus. In several such cases, lengthening of the gastrocnemius tendon, with splinting of the foot in dorsoflexion, has in a short time (from one to three months) resulted in return of voluntary power in the tibialis anticus and to a less degree in the extensors of the toes.

The defect in peroneal lesions presenting a return of voluntary power in the peroneus longus, without a corresponding recovery in the tibialis anticus, may with reason be attributed to the evil effects of overstretching. A failure of regeneration in the peroneus longus, however, indicates that extreme degree of atrophy and muscle degeneration which is so commonly found in the leg following prolonged sciatic paralysis; this regenerative muscular failure is also commonly observed in the smaller muscles on the dorsum of the leg. It may be roughly stated that between 40 and 50 per cent of failures in the return of dorsoflexion of the foot are due to overstretching.

There is a marked tendency for the gastrocnemius to develop contractures in all sciatic trunk lesions, as well as terminal peroneal lesions. The prevention of these contractures and their correction after development is of extreme importance. A patient with a sciatic or peroneal paralysis should be provided with a satisfactory foot-drop splint and the importance of its use strongly emphasized. Not only should a splint be applied to the shoe for day wear, but there should also be provided a night splint, and its persistent use should be

insisted upon. When contracture in the gastrocnemius has definitely developed, lengthening of the Achilles tendon should not be postponed, and the patient trained to assume, when sitting, a position which the writer has termed in his clinic, for convenience, "Achilles corrective habit posture," in which the patient stretches the Achilles tendon by resting the anterior part of the foot on the floor with the knee overflexed, exerting pressure by the weight of the opposite leg when crossed over the knee—the common habit of sitting with the knees crossed: i. e., the injured foot, while resting on the floor, is drawn backward in a position causing tension on the Achilles tendon, which is stretched by the superimposed weight of the opposite leg. The development of this habit corrective posture has proved of great value in stretching the Achilles tendon and relaxing the extensor muscles.

Secondary sutures should be attempted only for the correction of defective neuraxon regeneration, or for marked degrees of torsion. In resuturing the sciatic trunk or its terminal portions, identification sutures are not to be employed for surface identification, as the nerve may have suffered torsion in the original suture. In the sciatic trunk, the intraneural septum between its component tibial and peroneal portions will serve as a reliable guide in effecting physiologic approximation. In the popliteal portion of these nerves, anatomic or branch identification will serve in the correction of defects caused by torsion. (See technique for sciatic trunk and popliteal lesions, pp. 1051–56.)

SUPPLEMENTARY PROCEDURES FOR IRREPARABLE DEFECTS AND DEFECTIVE REGENERATION IN THE SCIATIC TRUNK AND ITS TERMINAL DIVISIONS

Though complete anesthesia of the foot follows total paralysis of the sciatic trunk, the sensory disability alone does not seriously interfere with locomotion. Undoubtedly, the greatest factor in the disability following complete sciatic paralysis is referable to the motor side. The loss of sensation in the foot, however, predisposes to traumatic insults, and a continued irritation of a traumatized anesthetic area may be serious in its consequences—though pressure sores are not usually so and will readily heal when the irritation is relieved.

In a series of more than 300 sciatic lesions, not a single instance was observed in which it was not possible to effect approximation of at least the tibial portion of the sciatic trunk; in about 80 per cent of cases followed, there has been a restoration of motor function to some degree, with a gradual disappearance of pressure sores. The motor defect consists chiefly in the loss of stability in the foot. In the majority of instances following sciatic suture, there has been a return of at least some useful power in the gastrocnemius, rendering plantar flexion of the foot possible, which assists in correcting much of the original disability. It is obvious that the tibial nerve from a functional standpoint is of more importance than the peroneal, and in continuity defects of both nerves resisting correction by every other means, the surgeon is justified in sacrificing the peroneal portion of the trunk, when the defect in the tibial can be corrected by the use of the peroneal as a transplant, in an effort to restore at least gastrocnemius function and sensation to the sole of the foot.

VIABLE NEUROPLASTIC TRANSPLANT FOR THE CORRECTION OF TIBIAL DEFECTS

First stage.—In this procedure, to assure viability of the graft, a two-stage operation is done, in which the proximal end of the sciatic trunk first receives attention. At the lower end, the line of cleavage between the peroneal and tibial portions is found and these respective elements separated for a short distance up the sciatic trunk. The ends of both nerves are now resected until normal appearing nerve bundles are found, they are then brought together and carefully approximated, making a loop of the distal end of the proximal segment of the sciatic trunk. The sciatic trunk is now followed upward for a distance a little longer than that necessary to fill the defect; at this point the line of cleavage between the peroneal and tibial portions of the nerve is identi-

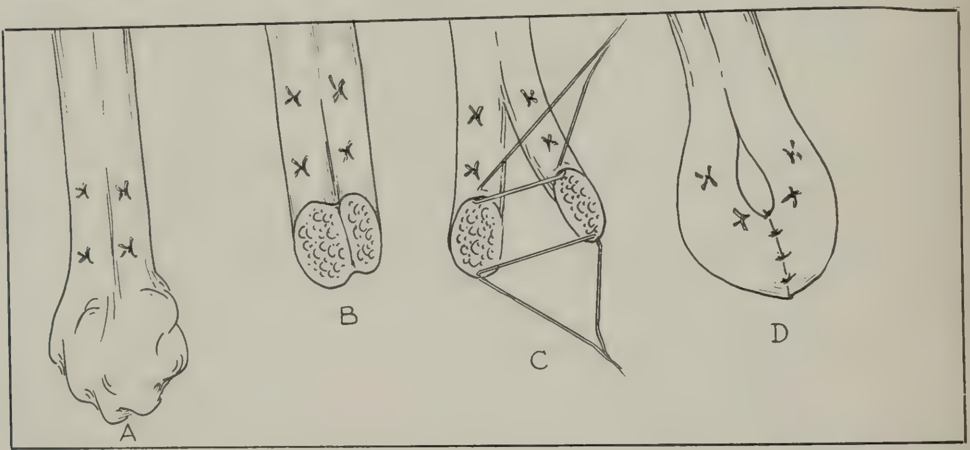

FIG. 198.—This and Figure 199 illustrate viable neuroplastic transplant for repair of tibial portion of sciatic trunk in irreparable lesions of both divisions. A, Exposure of proximal end of sciatic trunk; identification sutures placed; B, neuroma resected from both divisions; C, tibial and peroneal portions separated in line of cleavage to permit end-to-end approximation; D, end-to-end approximation uniting proximal end of tibial division to proximal end of peroneal division; E, peroneal division divided to permit degeneration of peroneal fibers in that portion of the trunk to be used as a transplant; upper end of peroneal portion injected with alcohol to prevent regeneration of peroneal fibers in transplant; F, peroneal transplant now becomes a viable part of the tibial portion of the nerve and presents a neuroma, showing complete migration of tibial fibers; G, transplant turned down and united to distal end of tibial division, filling the defect—peroneal portion having been sacrificed to repair the tibial. (See fig. 199)

fied and separated for a short distance to permit division of the peroneal portion. The purpose of this step is to permit degeneration in the anastomosed segment of the peroneal nerve, which is later to be reflected downward and attached to the distal segment of the tibial nerve as a viable transplant. This procedure will allow regeneration of the tibial fibers around the loop and up the intact transplant. The upper end of the peroneal nerve, proximal to the point where it is divided, is now injected with alcohol, or foreign tissues interposed to prevent regeneration of peroneal fibers down that portion which is to be used as a transplant. In this way, the viability of the transplant is assured during migration of tibial fibers.

If the transplant to be utilized is 6 inches long, the second stage of the operation is postponed for a period of seven months, allowing regeneration to proceed at the rate of 1 inch per month plus one month's grace. If the trans-

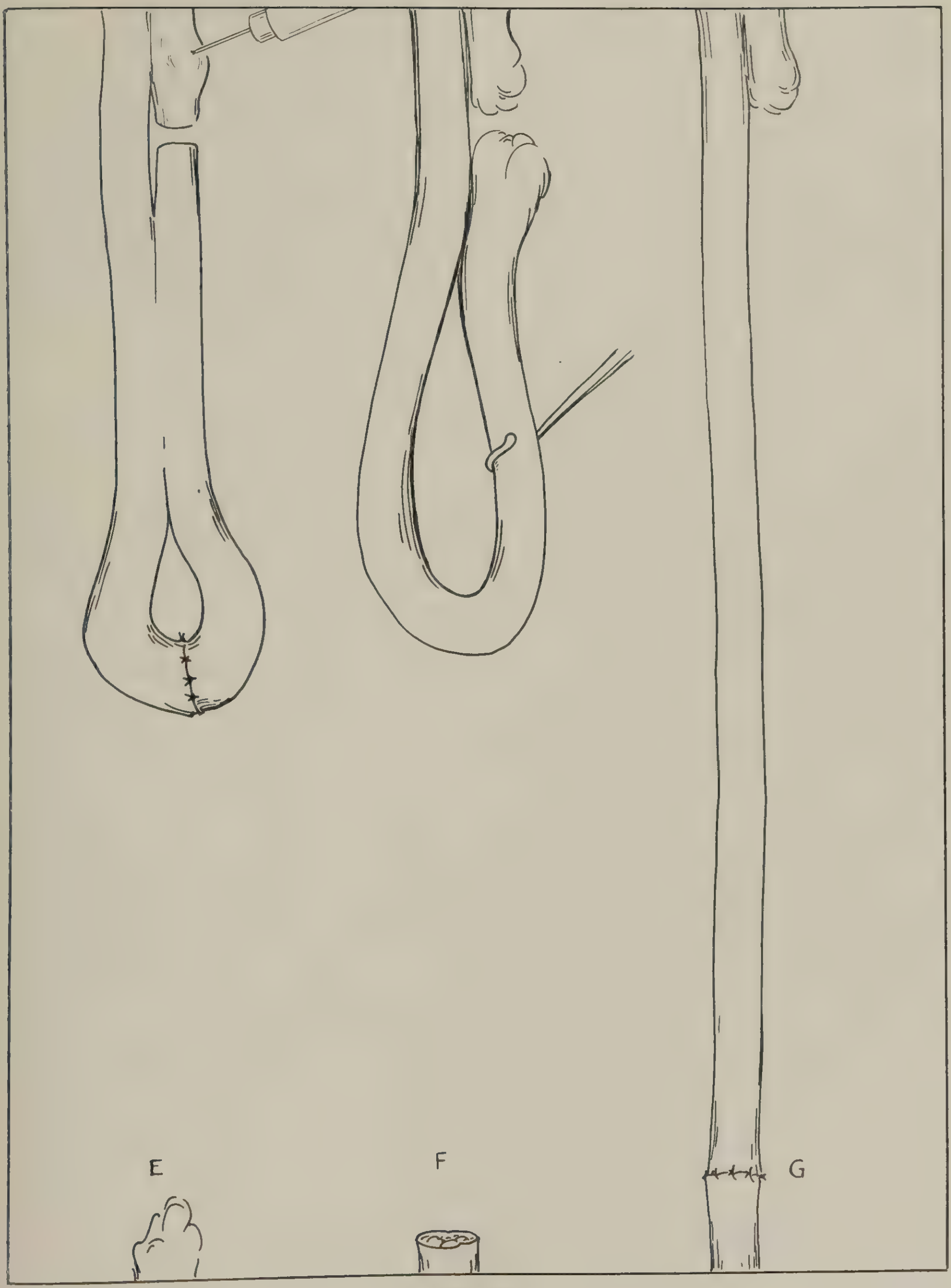

FIG. 199

plant is longer or shorter, the time of the second operation will be modified accordingly.

Second stage.—The sciatic trunk is again exposed above, and the tibial nerve below; and a favorable bed prepared to receive the regenerated transplant. The loop at the end of the sciatic trunk is isolated with great care and the line of cleavage between the tibial and peroneal (now transplant) portions of the trunk carefully separated up to a point where the peroneal was originally divided; the transplant is now turned down. The upper segment of the tibial nerve, with its viable transplant attached, is accurately approximated to the distal segment of the tibial nerve, after the scar tissue of both ends has been carefully resected. If the branches to the gastrocnemius are properly preserved, and their dorsal position in the tibial trunk borne in mind, and the approximation with the transplant is planned without torsion, a return of function in the gastrocnemius and sensation to the sole of the foot may be expected.

Inasmuch as voluntary dorsal flexion of the foot is permanently lost, the drop-foot may be corrected by arthrodesis of the ankle joint or tendon slinging—no muscles being available to restore by tendon transplantation the lost function of the anterolateral group of muscles supplied by the peroneal nerve. Arthrodesis stabilizes only the posterior portion of the foot without giving support to the toes; in certain cases it seems to be valuable but occasionally it is attended with end results entirely unsatisfactory to the patient. Tendon slinging is by far most satisfactory of these procedures for the correction of drop-foot in irreparable nerve lesions. It consists in suspending the foot by passing the upper part of the tendon of the tibialis anticus and peroneus longus through a hole in the shaft of the tibia, where they are anchored; and supplementing this suspension with the peroneus brevis; the extensor tendons of the toes are used to suspend the anterior part of the foot.

Technique

A long incision on the anterolateral surface of the leg, midway between the crest of the tibia and the fibula is carried down to the ventral aspect of the ankle joint, midway between the two condyles. As it reaches the annular ligament it curves to the outer side of the foot, below the external malleolus, to expose the peronei tendons. The tendon of the tibialis anticus is now isolated and freed from muscle fibers to a point about 6 inches above the annular ligament. The tendons of the extensors longus hallucis and digitorum are treated in a similar manner. The peronei tendons are exposed by undermining the lateral border of the incision; after being mobilized, they are divided at the upper end of the incision. They are again exposed and their sheath opened on the lateral border of the foot; after having been withdrawn from their sheath they are directed anterior to the condyle, through a passage made under the annular ligament. A hole through the crest of the tibia is now made by a gouge, the tendon of the tibialis anticus drawn through from the medial side, and the tendon of the peroneus longus passed through from the lateral side. With the foot held in dorsal flexion, at a right angle to the tibia, and neutral to inversion and eversion, the tendons are drawn taut, the angle of flexion being slightly overcorrected; they are then fixed with strong linen sutures. Ex-

perience has shown that it is advisable to supplement this procedure by also suspending the tendons of the peroneus brevis, extensor longus digitorum, and extensor longus hallucis; which is effected by suturing them to the transplanted tendons of the tibialis anticus and peroneus longus, the combined group of tendons being too large to be passed through the hole in the tibia. It is essential that the foot be kept slightly overflexed and straight, and each tendon attached individually, after its tension has been properly adjusted. After six weeks, the plaster cast may be disregarded; a shoe fitted with a drop-foot splint should, however, be worn during the day and a drop-foot bed splint used at night. Walking on the foot without a suitable drop-foot splint should not be permitted until after the third or fourth month, by which time the tendons should be firmly fixed in hardscar tissue.

FACIAL NERVE

FACIAL PARALYSIS

Most surgical lesions of the peripheral portion of the facial nerve are found in its course through the facial canal in the temporal bone, where it is occasionally involved in skull fractures or injured during operations for mastoid disease. Its most frequent affection, however, is that type of facial paralysis termed Bell's palsy, with a common history of "exposure to cold." Its long course through the facial canal, which it almost completely fills, renders it particularly susceptible to injury or disease in this region; it may be completely severed or crushed by fragments of bone during a mastoid operation, or compressed by inflammatory exudate, hemorrhage, or congestion. Bell's palsy is a compression paralysis due to congestion or an inflammatory affection from exposure. Congestion of the facial nerve in this region is particularly serious because the nerve is unable to expand, being completely surrounded by a bony wall, and any congestion or inflammatory exudate is rapidly converted into a compressive agent. The nerve, after its exit from the stylomastoid foramen, is occasionally injured by stab or gunshot wounds; as it passes through the parotid gland it may be compressed by suppurative processes or neoplasms. Injuries distal to the parotid gland, unless very extensive, seldom implicate the complete nerve, usually involving only one or more of its terminal branches.

Fig. 200.—Dissection of temporal bone, showing course of facial canal in its vertical and tympanic portion—wire directed through canal. Posterior to the bend is the eminence of the lateral semicircular canal; anterior to the nerve lies the tympanic cavity. Note the straight course of the nerve from its position anterior and below the eminence of the lateral semicircular canal to the stylomastoid foramen. Identification of the nerve at these two points—just below the lateral semicircular canal and at the stylomastoid foramen—is the keynote to the exposure of the nerve through its vertical course. (Ney. *The Laryngoscope*, 1922)

Many facial palsies of the compressive type recover spontaneously, as the congestion or inflammatory exudate responsible for the paralysis subsides. After surgical division during mastoid operations, if the facial canal is not blocked

by bone fragments or scar tissue, the nerve will usually regenerate. If spontaneous regeneration progresses satisfactorily, the facial muscles should show signs of recovery before one year, and in each instance this period should be allowed to lapse before a decision of nonregeneration is definitely made. During this expectant period it is essential that the facial muscles be properly splinted to prevent overstretching, which frequently is responsible for much delay in muscle regeneration.

NERVE ANASTOMOSIS IN FACIAL PARALYSIS

Frequent attempts have been made to correct facial paralysis by anastomosing the spinal accessory or hypoglossal nerve to the facial. In this procedure the facial nerve is exposed at its exit from the stylomastoid foramen and divided; the hypoglossal or spinal accessory, whichever may be selected, is next exposed and divided and its proximal end approximated to the end of the distal segment of the facial. The regenerating spinal accessory or hypoglossal fibers will now pass through the peripheral facial trunk to the facial musculature; after a period of five or six months these muscles will regain their tone—providing regeneration has been satisfactory—and the face will show great improvement during repose. The facial muscles, however, fail to react to emotional expression, and to all intents and purposes remain totally inactive until called into play by spinal accessory or hypoglossal impulses. If hypoglossofacial anastomosis has been done, the facial muscles will contract vigorously during mastication and deglutition; after facio-accessory anastomosis, the facial muscles will react during turning of the head or elevating of the shoulder. These facial movements, following facial nerve anastomosis, are entirely irrelevant to emotional expression, and occasionally are extremely embarrassing, in attempts to swallow or lift the shoulder will inaugurate winking or drawing up the angle of the mouth. Some writers have recommended the use of the hypoglossal nerve for anastomosis in facial paralysis in preference to the spinal accessory on the ground that anatomic proximity of the facial and hypoglossal center in the cortex might facilitate reeducation. Experience seems to indicate that the conversion of the hypoglossal center to facial function is not readily, if ever, accomplished. Ney has not observed a single instance of nerve anastomosis in which any of the coordinated movements required in facial expression have been regained, though he has had under his observation several cases which, for a period of eighteen months, received constant daily instruction under the direction of experienced teachers. It has been possible to train certain favorable cases to a point where they would be able to effect satisfactory isolated closure of the eye, or contraction of the muscles about the corner of the mouth, without synchronous movements in the shoulder or tongue; coordinated emotional movements, however, were totally lacking in spite of all reeducative endeavors; the hypoglossal or the spinal accessory fibers remain hypoglossal or spinal accessory fibers from a functional standpoint and probably never will be able to subserve any other function. The most that may be said in favor of nerve anastomosis for the correction of facial paralysis is that, in favorable cases, there will be a restoration of tone in the facial muscles; it is usually associated with more or less embarrassing incoordinated facial move-

ments which are incited by hypoglossal or accessory stimuli. The operation of nerve anastomosis for the correction of facial paralysis is now being generally abandoned.

The possibility of recovering coordinated emotional expression in the paralyzed facial muscles probably lies only in restoring the physiologic continuity of the facial nerve. This procedure has generally been considered impractical from a surgical standpoint, because of the difficulty involved in isolating and repairing the facial nerve. Ney, however, has devised a technique by which the facial nerve may be satisfactorily exposed and repaired in that portion of the facial canal where it most frequently suffers trauma, namely, in its vertical or tympanic segment.

TECHNIQUE OF EXPOSURE AND REPAIR OF THE FACIAL NERVE THROUGH ITS COURSE IN THE TEMPORAL BONE FROM THE GENU OF THE FACIAL CANAL TO THE STYLOMASTOID FORAMEN

The incision corresponds to that commonly used in the radical mastoid operation, except that it is extended forward, above the ear, to expose the zygomatic tubercle; below it is extended from 1 to 2 inches beyond the mastoid tip, following the anterior border of the sternomastoid muscle. Through this incision the mastoid bone is exposed and the soft parts reflected from the entire mastoid process, completely exposing the mastoid tip, during which care should be used to prevent injury to the nerve as it emerges from the stylomastoid foramen. The soft parts should be thoroughly freed from the under surface of the auditory process of the tympanic plate. The stylomastoid foramen is located about 7 millimeters in front of the tip of the mastoid; its depth from this point varies considerably, depending upon the extent of mastoid development. In infants, before the mastoid has developed, the facial nerve emerges from the stylomastoid foramen directly on the surface of the skull, where it may be injured in the application of forceps. With the development of the mastoid, the stylomastoid foramen becomes covered with the mastoid tip and the auditory plate of the tympanic ring. The cartilaginous portion of the external auditory meatus is entirely separated from its bony wall, except in its anterior portion. Its attachment to the auditory process is usually firm, because of the roughened character of the bone in this region. It is important, however, that the auditory plate be well exposed.

The auditory plate of the tympanic ring is now removed by a sharp chisel or strong rongeurs. This removal should be executed with considerable care to prevent fracture of the tympanic ring, the bone being cut down rather than broken down. The removal of the tympanic plate is the key to the situation, in so far as locating the stylomastoid foramen is concerned. The auditory process now having been removed, the operator may proceed with the removal of the mastoid cortex and cells. The mastoid antrum is located as in the usual mastoid operation. The mastoid cells are now thoroughly removed, endeavoring to keep the cavity as shallow as possible by trimming down the rim left by their evacuation; this is particularly important in the suprameatal region, where the cortex and cells of the posterior zygoma should be removed completely as far

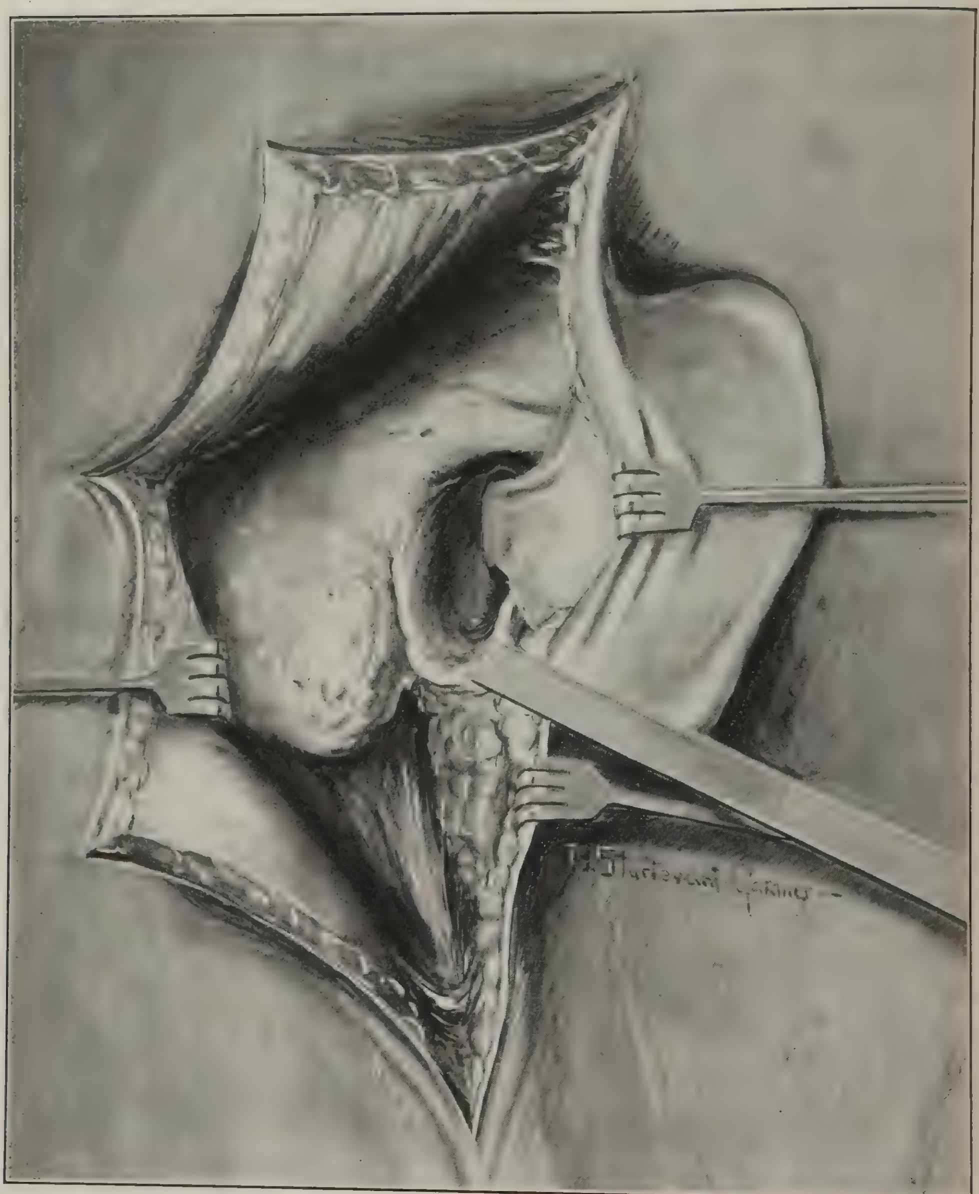

FIG. 201.—Primary incision and exposure of the mastoid tip, suprameatal ridge, superior, posterior, and inferior bony meatal walls. The chisel shows point at which removal of auditory plate is begun, to permit exposure of the stylomastoid foramen. (Ney. *The Laryngoscope*, 1922)

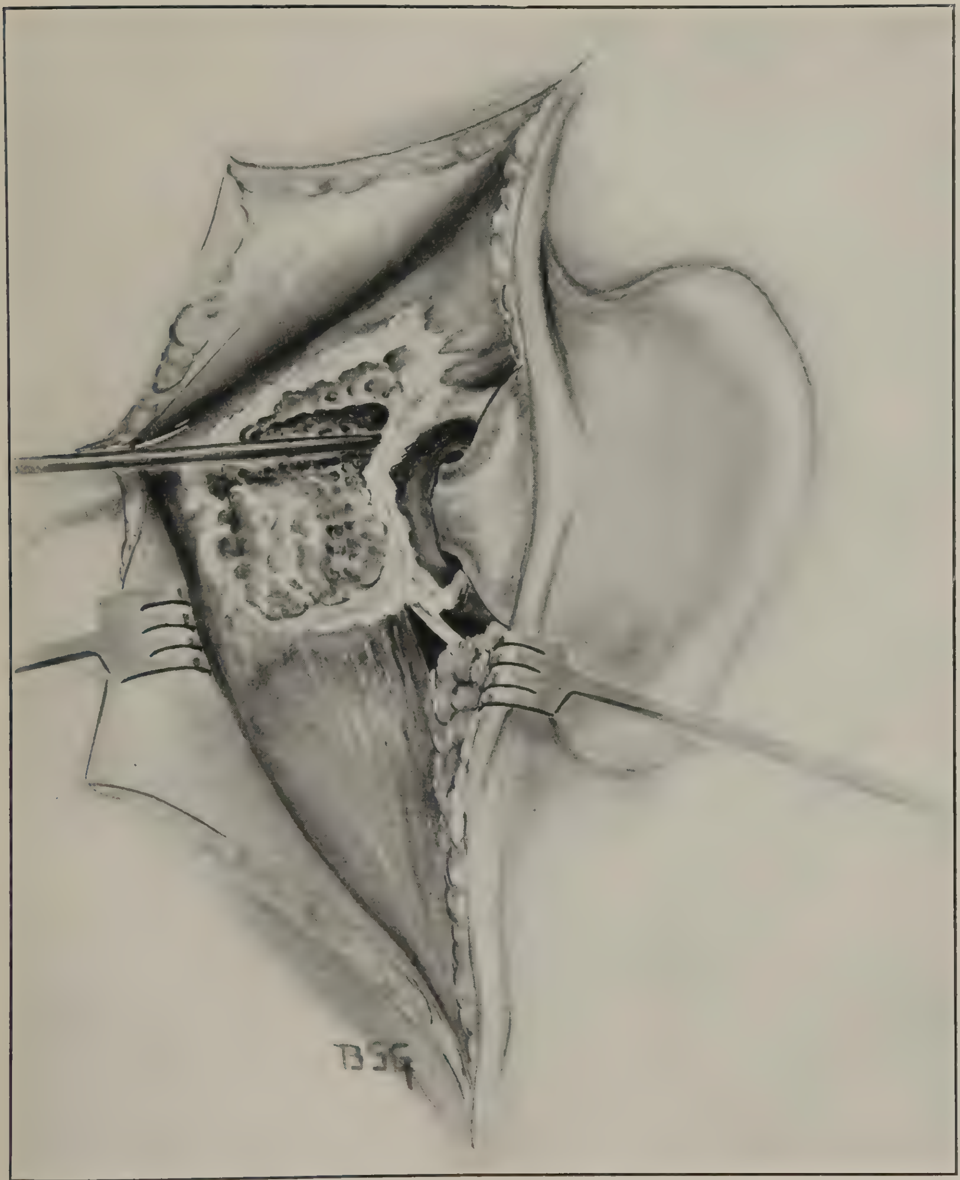

FIG. 202.—Auditory portion of the tympanic bone, partially removed, exposing the exit of the facial nerve from the stylomastoid foramen to where it passes into the substance of the parotid gland. Mastoid cortex removed and cells evacuated—probe passed into antrum; suprameatal ridge partly removed. (Ney. *The Laryngoscope*, 1922)

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FIG. 203.—Bridge formed by the posterior meatal wall broken down over antrum, exposing the eminence of the lateral semicircular canal; suprameatal ridge not sufficiently broken down. (Ney. *The Laryngoscope*, 1922)

forward as the zygomatic tubercle. Frequently it is necessary to expose the dura to gain sufficient depth in this region.

The mastoid tip is entirely removed and the facial nerve exposed as it emerges from the stylomastoid foramen. Occasionally the localization of the nerve is attended with some difficulty; its identification is often facilitated by palpation, when it is felt as a tense cord passing from the stylomastoid foramen to the parotid gland. The difficulty usually lies in attempting to locate the nerve in the region of the mastoid tip, when in the majority of instances it is to be found anterior to the tip. The posterior meatal wall may

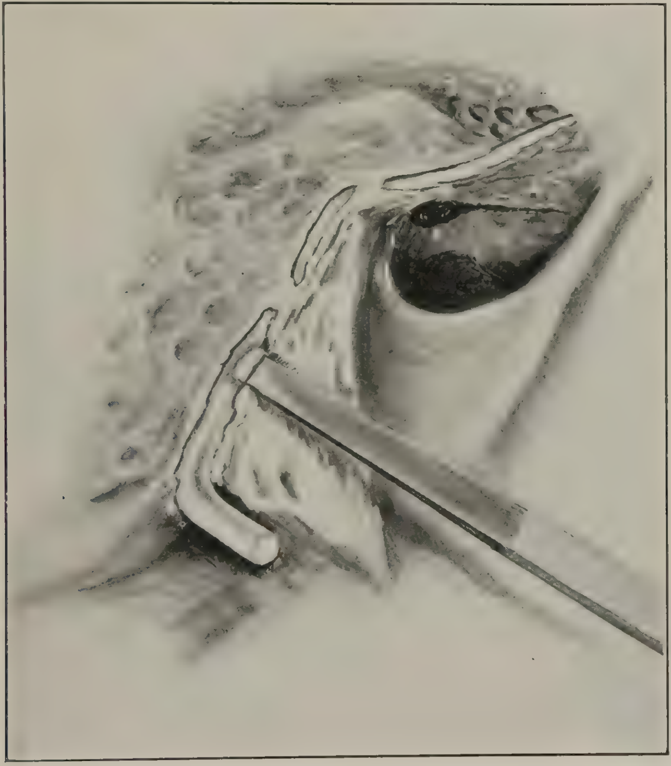

FIG. 204.—Facial nerve uncovered through a portion of its vertical and tympanic course, showing method of breaking down the wall with a fine, sharp chisel. (Ney. *The Laryngoscope*, 1922)

now be reduced to the level of the mastoid evacuation; that portion overlying the mastoid antrum is entirely removed. If an attempt is made to break down the antrum with a chisel, great care should be used, as the chisel in breaking through the bridge may traverse the antrum and enter the facial canal, or the dislodged bone driven into the canal. There is no doubt but that the facial nerve is frequently injured during this procedure in the radical mastoid operation. The prominence of the lateral or external semicircular canal is now identified and immediately anterior to this structure, between it and the tympanic cavity lies the prominence of the facial canal. Occasionally, in this region the facial nerve will be found exposed through a defect in the canal wall.

If during the evacuation of the mastoid cells any suppurative process is uncovered, it should be thoroughly eradicated and the exposure and repair of the facial nerve postponed until the infection is entirely controlled. If it is deemed necessary to drain the mastoid, the second operation is not to be considered until the mastoid wound has been completely healed for three months and the ear free from all discharge, or sterile to culture.

The stylomastoid foramen, having been exposed below, and the facial canal located anterior to the lateral semicircular canal, the operator may now definitely orient the course of the vertical segment, which follows a direct vertical line between these two points. The reduction of the posterior meatal wall and mastoid cells may now be safely conducted to the level of these points, without fear of injuring the nerve. The vertical portion of the canal, which is about 1 mm. in diameter, lies, in the average case, about 3 mm. behind the posterior meatal wall; frequently the canal is exposed as a ridge of compact bone, though occasionally cells may open directly into it. After the mastoid has been reduced to about the level of the canal wall, the lateral or exposed side of the canal wall is carefully scaled off with a small sharp chisel, beginning at the stylomastoid foramen and progressing upward to the bend of the canal.

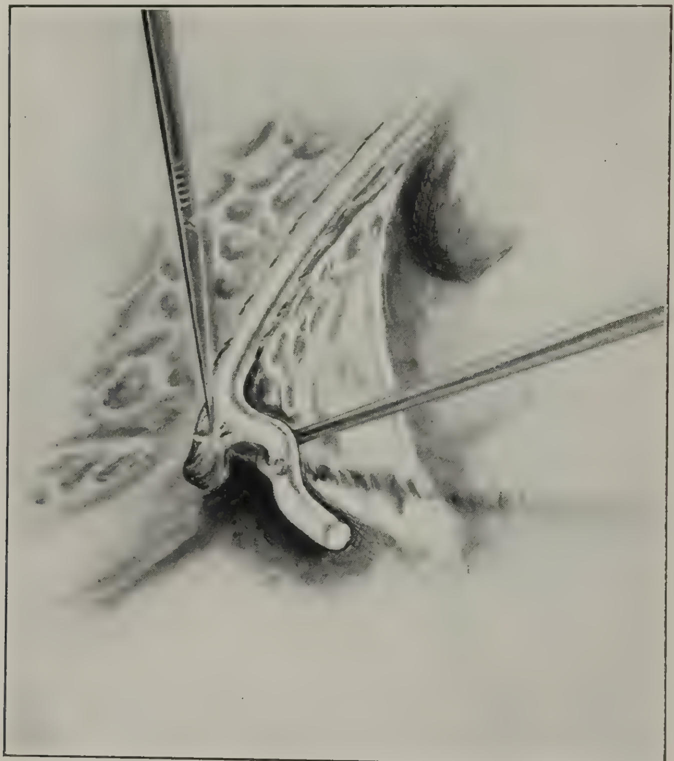

FIG. 205.—The sheath of the facial nerve is firmly attached to the periosteum of its canal; its attachment is severed with a cataract knife, while the nerve is gently lifted from its bed. In this region the facial nerve is very fragile and gentleness is necessary to prevent tearing the nerve trunk. (Ney, *The Laryngoscope*, 1922)

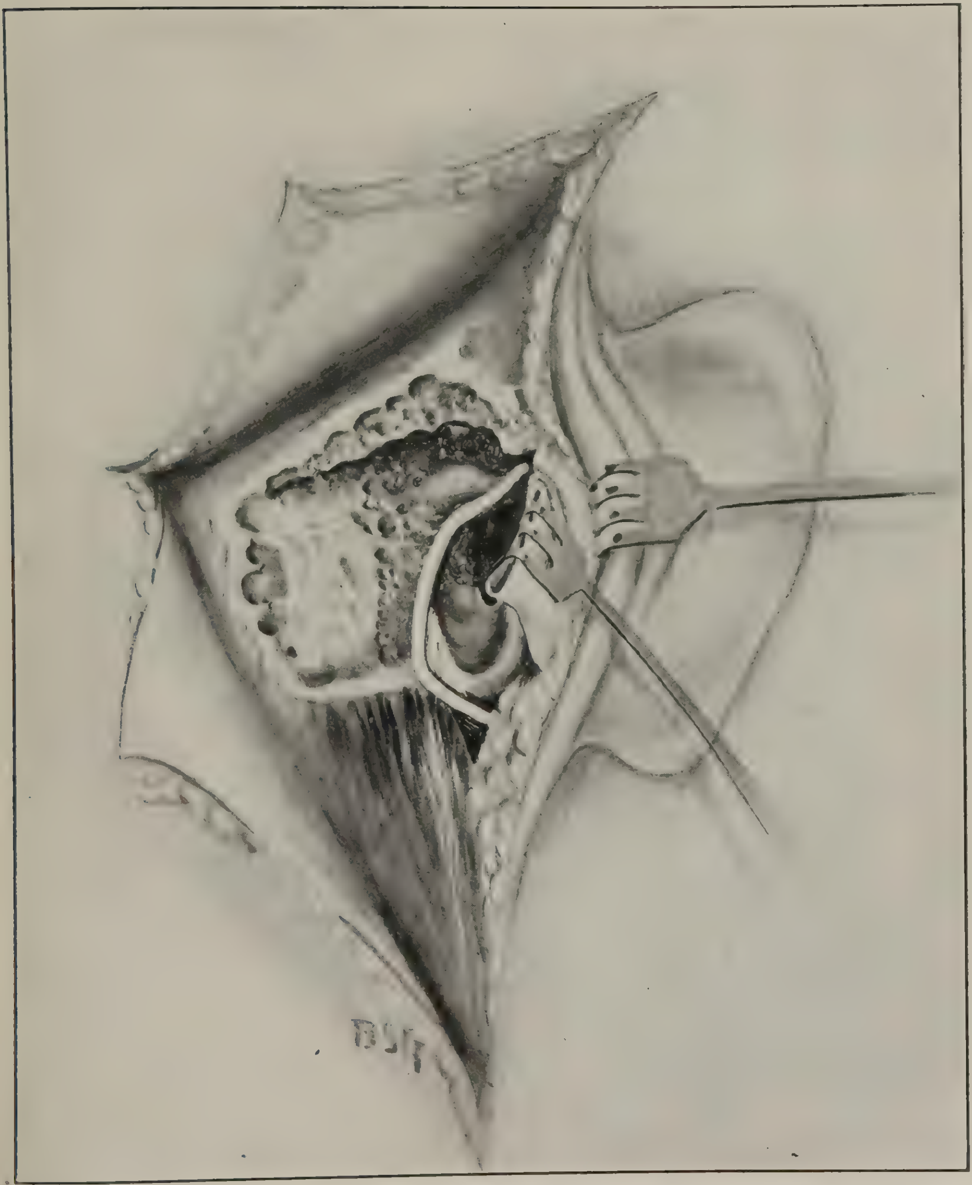

FIG. 206.—The nerve removed from the facial canal throughout its vertical and tympanic course. (Ney. *The Laryngoscope*, 1922)

Occasionally, the canal is separated from the mastoid cells by 1 or 2 mm. of solid bone; at other times it is only a thin shell.

The vertical segment of the canal extends from the stylomastoid foramen to the "bend" or the pyramidal segment, which lies in front of the lateral semicircular canal and constitutes that portion of the canal where its direction changes from the vertical to the horizontal; the bend is usually gradual, implicating from 2 to 6 mm. of the canal, though occasionally the direction changes

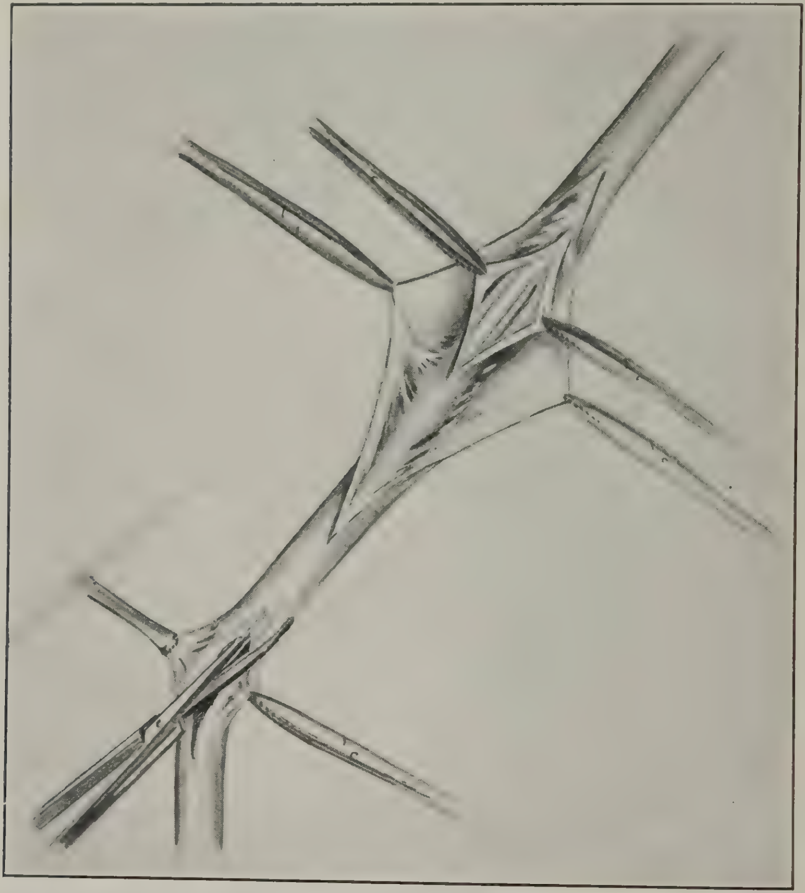

Fig. 207.—Decompression of the facial nerve by opening its sheath. Diagram shows the attachment of the sheath of the facial nerve to the periosteum of the canal, which has been preserved in the dissection. The sheath of the facial nerve is opened, exposing fibers which appear as a pearly white bundle. (Ney. *The Laryngoscope*, 1922)

with a sharp angle. The tympanic segment of the canal constitutes its horizontal portion, which extends from the pyramidal segment to the genu and passes along the roof of the tympanum; its average length is about 8 mm. In its horizontal course, the canal undergoes a gradual steady rise in level, reaching the junction of the roof and inner wall, where it leaves the tympanic cavity to form the genu. About midway in its course it comes in close relationship with the fenestra ovale and stapes. After forming the genu, the canal gently curves toward the cochlea and tunnels the dense petrous portion of the bone throughout

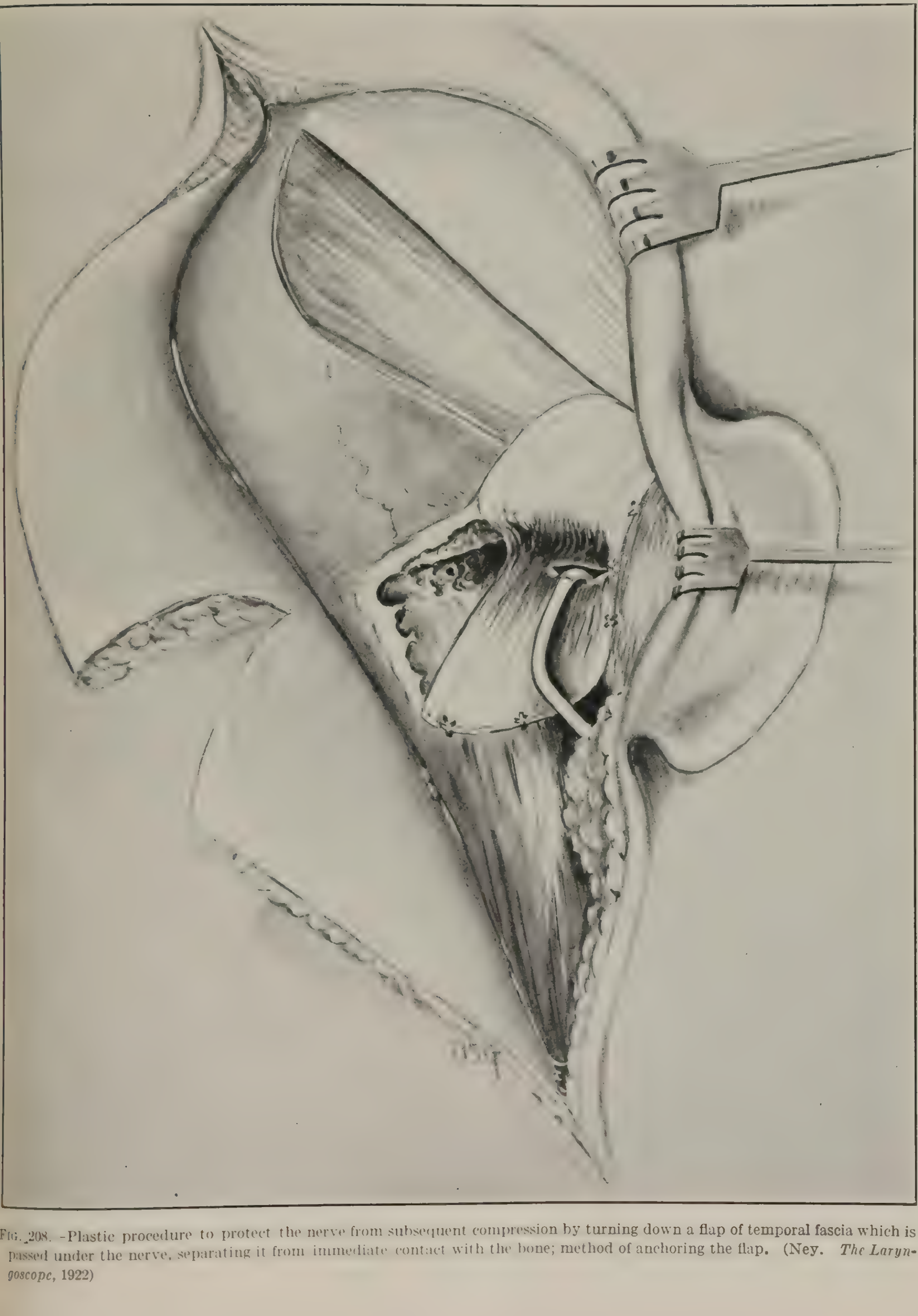

FIG. 208.—Plastic procedure to protect the nerve from subsequent compression by turning down a flap of temporal fascia which is passed under the nerve, separating it from immediate contact with the bone; method of anchoring the flap. (Ney. *The Laryngoscope*, 1922)

its course, independent of the contour of the upper surface of the bone. This, the labyrinthine section of the canal, extends from the genu to the lamina cribrosa.

After the vertical segment of the facial nerve has been uncovered, the operator, by the same process of careful scaling, may uncover the nerve through its pyramidal and tympanic portions, the canal wall being gradually reduced until the nerve is well exposed. In cutting away the wall of the facial canal, fragments of bone will be found firmly attached to the periosteum of the canal and should be dissected rather than torn away; the sheath of the facial nerve is intimately attached to the periosteum of the canal, and the tearing away of attached fragments may injure the nerve, which is extremely fragile. The separation of the nerve from the canal wall is begun at the stylomastoid foramen, where it is elevated on a fine glass hook, and the attachments of the periosteum to the bone are divided by a fine-pointed cataract knife. During dissection of the facial nerve, the operator should take time to control oozing—a fine stream of warm saline is usually effective.

With the above mobilization of the nerve, the nature of the lesion will probably be apparent. If the nerve is not found to be divided, it has probably been subjected to compression, but careful inspection is required, as its ends may be united by scar tissue. If it is completely divided, it may be sutured, after the scar has been resected from its ends, with arterial silk, care being used to prevent torsion of the nerve trunk, the center of the exposed quadrant of its sheath having been previously marked by identification sutures. The needles used are Lane's half-curved cleft-palate needles, No. 3, which are of very small size and may be handled by mosquito forceps. If the nerve is found to be the subject of compression, it should be decompressed by carefully splitting its sheath with a cataract knife, exposing its pearly white bundles; as the point of compression is reached, these bundles are often pinkish in color. If, in opening the sheath, an area of scar invasion is met (in which the bundles lose their identity) this area must be resected and the nerve approximated by end-to-end suture. If approximation is found difficult, because of a continuity defect in the nerve, the lower segment of the nerve should be mobilized as far forward in the parotid gland as possible. This mobilization, by permitting the nerve to take a more direct course, will frequently facilitate the correction of a defect up to 1 cm. The mobilization of the facial nerve may be somewhat increased by uncovering its proximal end to the genu of the canal, when it may be transposed; the anterior part of the cartilaginous portion of the external auditory meatus is separated from its bony wall and the entire ear turned forward; the nerve when sutured is made to pass anterior to the cartilaginous portion of the meatal canal, instead of assuming its orignal posterior position. After transposing the facial nerve to the anterior position, the cartilaginous canal is replaced and sutured. The mobilization of the proximal end of the nerve is greatly facilitated by reducing the suprameatal wall, and removing as far internally as necessary the superior surface of the petrous portion of the temporal bone, after elevating the dura until the genu of the canal is fully exposed. When this procedure fails to overcome a continuity defect, recourse may be had to grafting, when a sensory

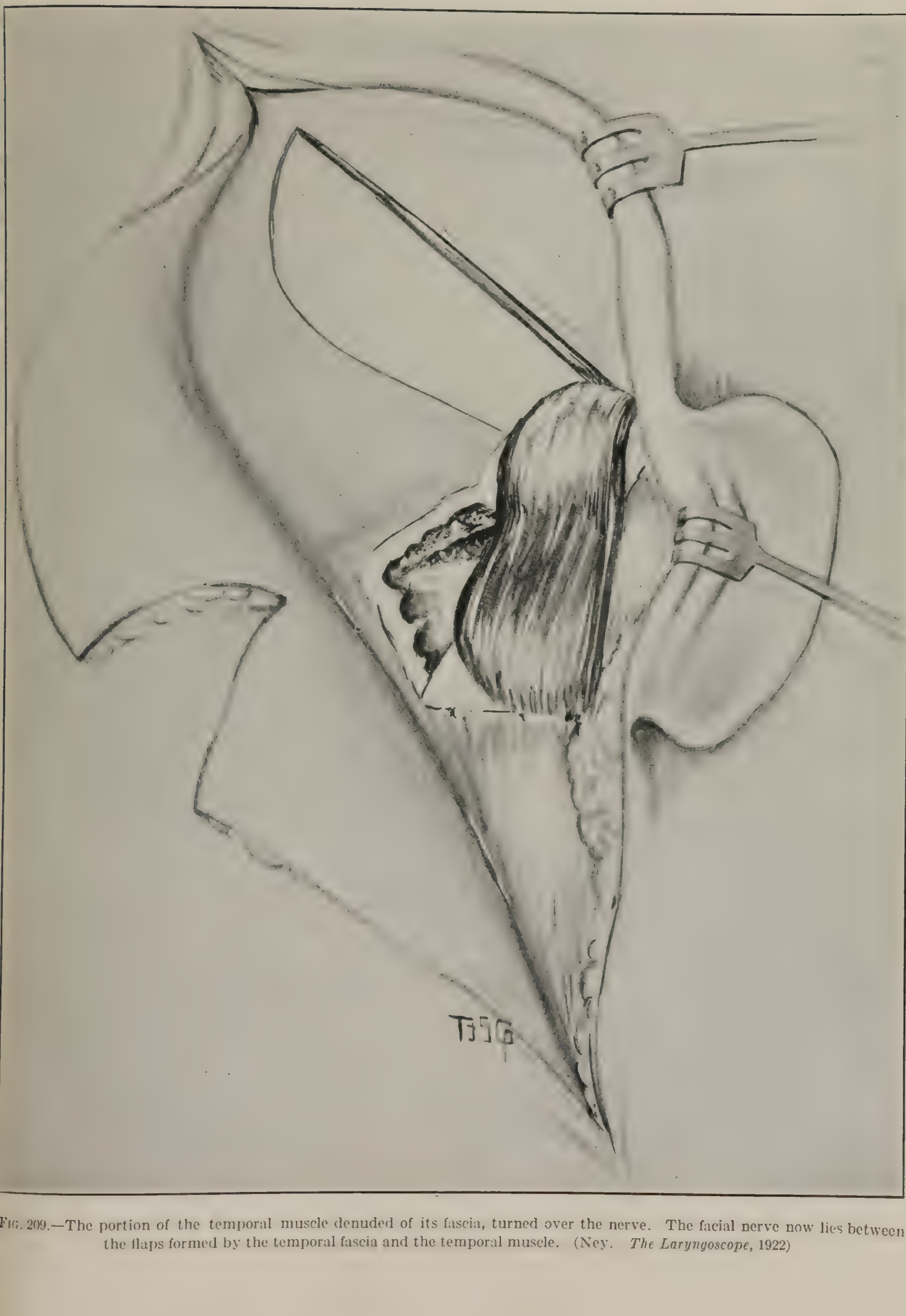

FIG. 209.—The portion of the temporal muscle denuded of its fascia, turned over the nerve. The facial nerve now lies between the flaps formed by the temporal fascia and the temporal muscle. (Ney. *The Laryngoscope*, 1922)

nerve of approximate size may be inserted to fill the defect. It has not been found necessary to resort to a graft of this kind in any of the cases.

The preparation of a bed for the repaired nerve is a rather difficult procedure. Occasionally the question may be solved by transposing the nerve to a position anterior to the cartilaginous meatus. In all decompressions and occasionally after suture, the writer has protected the nerve by turning down a flap of the temporal fascia and muscle, the muscle being used to cover the nerve, while the smooth surface of the temporal fascia is passed under the nerve to protect it from immediate contact with the bone.

The incision is closed by interrupted sutures; three small rubber drains will usually be found sufficient to care for the rather abundant oozing following the operation. These drains are allowed to remain in place for 48 hours. A 5 per cent dichloramine-T solution is instilled into the middle ear, and the external auditory meatus lightly packed with gauze. If, during the course of the operation, the ossicles have been completely removed, the external auditory meatus may be obliterated by suturing together the cartilaginous canal before the skin is closed. If this is done, a drain is placed from the mastoid incision directly into the middle ear, and the condition of the wound carefully watched.

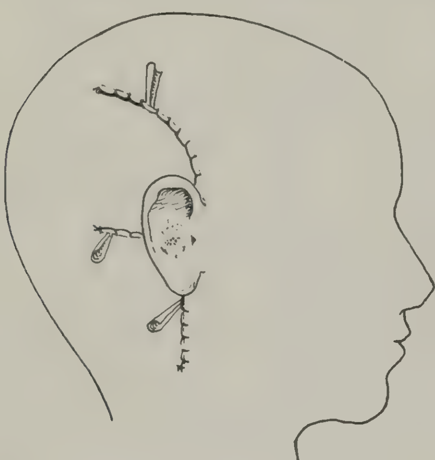

FIG. 210.—Incision closed; points of drainage indicated. External auditory meatus lightly packed with iodoform gauze. (Ney. *The Laryngoscope*, 1922)

The after-treatment consists mainly in preventing overstretching of the paralyzed facial muscles by the application of adhesive straps, as suggested by Yawger; or by retracting the angle of the mouth with a hook, the hook being held by a piece of string or tape, which is tied to adhesive, attached to a shaven portion of the scalp above the ear back of the hair line, and kept under sufficient tension to prevent overstretching of the paralyzed muscles during laughter.

The exposure and repair of the facial nerve in the temporal bone is a practical, though very delicate, procedure, and one requiring considerable patience. Each step of the procedure should be carefully and completely executed; a little carelessness here or there may jeopardize the entire operation. Before attempting this procedure clinically, the operator should thoroughly familiarize himself with the anatomy by making several complete facial nerve exposures in the dissecting room. It is not necessary to use any especially made instruments in this operation; it is essential, however, that the surgeon be equipped with the smallest size chisels, gouges, and osteotomes.

CHAPTER XII

RESULTS OF PERIPHERAL NERVE SURGERY[a]

INCIDENCE OF PERIPHERAL NERVE INJURIES

Of the 174,296 battle injuries in the American Expeditionary Forces,[1] there were under treatment in military hospitals in the United States on May 1, 1919, 2,347 patients with 2,707 nerve injuries. The total number of nerve injuries could not accurately be determined in view of the fact that in many instances patients suffering from such injuries were admitted to hospital for other conditions with which the nerve injuries were associated. However, it was estimated at the time in question that 30 per cent of the patients with nerve injuries either were on furlough or had been discharged. Taking this number into consideration, as well as the comparatively small number of patients with nerve injuries who inadvertently had been sent to hospitals other than those designated for the purpose, the total number of peripheral nerve injuries was estimated as being 3,500, or about 2 per cent of the total number of battle injuries.

ORGANIZATION FOR THE CARE AND STUDY OF PERIPHERAL NERVE INJURIES

Relatively few operations for the repair of peripheral nerve injuries were performed in the American Expeditionary Forces; consequently, in anticipation of the arrival of such cases in the United States, certain general hospitals throughout the country were designated for their special care.[2] In each of these hospitals, known as peripheral nerve centers, carefully selected, experienced neurosurgeons had been placed, and in each there were well organized physiotherapy and educational departments. In passing, it may be added that, although there were 12 of these peripheral nerve centers, the major portion of neurosurgical operations were performed in six of them. On January 29, 1919, the Surgeon General appointed a peripheral nerve commission,[3] whose function it was to study and correlate the cases of peripheral nerve injuries. To make possible such study and correlation there was issued to each center a prescribed form, the peripheral nerve register, upon which was recorded the physical findings. Duplicates of these registers were deposited in the Surgeon General's Office upon the discharge of the patients concerned.[4]

With an organization thus effected in the peripheral nerve center for the management of peripheral nerve lesions, under conditions approaching the ideal, it was hoped that this organization might be continued for the determination of end results under equally ideal conditions. This hope, however, was not realized. During 1919, the supervision of neurosurgical cases, remaining under observation and seemingly not requiring operative treatment, was

[a] The facts contained herein are based, in the main, on "A General Discussion of the Operative Treatment and the Results in Three Thousand Five Hundred Peripheral Nerve Injuries of the American Expeditionary Forces," by Lieut. Col. Charles H. Frazier, M. C., read before the International Surgical Society, London, July 19, 1923.

transferred to the United States Public Health Service, under the Bureau of War Risk Insurance.[5] In 1921, a further change in supervision was made. The Veterans' Bureau now took over, from the Public Health Service, the care of such patients still under treatment, or on a compensable status.[6] Thus, to follow a certain number of the nerve injury patients, it was necessary to deal with them, at different times, through three Government agencies.

TECHNIQUE

When comparing one series of statistics with another, or in correlating any individual series of operations from the standpoint of end results, the time element must be taken into consideration. It is generally conceded that the sooner the operation is performed after the injury the better the prognosis, and it has been stated that the results of nerve suture performed within the first 12 months after injury are better than those between 12 and 24 months or later. An attempt to confirm this statement by comparison of statistics in this series, however, failed.

It was a general practice in the peripheral nerve centers to postpone operation until three months after the wound had healed, and as the majority of the nerve injury cases had infected wounds on their arrival at the hospitals, the time of operation was deferred from four to eight months. In a series of 400 cases in General Hospital No. 11, in 31.5 per cent the operation was deferred to the end of the fourth month, in 41 per cent to the end of the fifth or sixth month, and in 15.5 per cent to the end of the eighth month (Table 9).

TABLE 9.—*Data concerning time of operation in a series of 400 cases of peripheral nerve injury*

Time required for healing prior to operation	Cases	Time when operation was performed after wound healed	Percentage
1 month or less	126	4 months	31.5
2 months	90	5 months	22.5
3 months	74	6 months	18.5
4 months	36	7 months	9.0
5 months	26	8 months	6.5
6 months	17	9 months	4.3
7 months	6	10 months	1.5
8 months	6	11 months	1.5
9 months or over	19	12 months	4.7

To wait for spontaneous regeneration longer than the sixth month is not considered justifiable, although it is well known that the first clinical signs of spontaneous regeneration may be deferred much longer. One case of musculospiral paralysis was observed in which the first sign of the return of voluntary motion did not appear until 21 months after the injury.

While the majority of the operations in the peripheral nerve centers were performed between October, 1918, and August, 1919, that is within a year of the injury, a not inconsiderable number of nerve sutures were performed at later dates, mostly on patients who, in times of overcrowding, had not passed through the peripheral nerve centers. These patients with their untreated lesions were discovered as they appeared for reexamination and adjustment of compensation.

During the period of reconstruction one relied upon the various signs of recovering function to determine whether spontaneous regeneration was in process or not, such as contraction of the field of sensory loss, the return of muscle tone, the changing electrical reactions, and the advancement of Tinel's sign. The latter, however, did not prove to be an infallible guide. Unfortunately, it was not until 1922 that a more accurate clinical method of determining the early recovery of a degenerated nerve was elaborated.[7] With the aid of a specially constructed chronomyometer, the nerve-muscle complex was found to disappear as early as the fifth day after the muscle was cut; it begins to appear from one to six months before a faradic response, from one week to three months before voluntary contractions and from zero to five months before contraction of the anesthetic area. This instrument offers an accurate index of the return of the progress of nerve regeneration and would have been invaluable during the period of reconstruction in the selection of cases appropriate for nerve suture.

The indications for resection admit of little discussion; resection was recommended, when six months after injury the lesion was stationary, when there was evidence of a complete anatomical interruption, when there was an interstitial neuritis or a neuroma in continuity, without response to stimulation, especially if the neuroma was imperfectly encapsulated.

It was generally conceded that one should resect sufficient of the damaged nerve to expose normal fasciculi, that is, above the seat of fibrosis. In some instances one had to stop short of conditions ideal for resection because the defect might be irreparable. A thickened nerve sheath in some instances was helpful, giving a better purchase to the suture under conditions of extreme tension. To relieve compression this nerve sheath, under these circumstances, was split longitudinally after approximation was effected.

Coaptation was effected with six to eight epineural silk sutures, and in many instances, when required to relieve tension at the line of suture, stay suture of catgut was employed. In tying the stay suture care was taken to avoid either crowding or a dead space between the peripheral and central segments. It has been claimed that an intraneural suture stimulates connective tissue formation, but the frequency with which the stay suture was used and the results obtained, must stamp this objection as of theoretical rather than practical import.

In the writer's experience it was only in an exceptional case that a partial resection seemed indicated and usually in the lesions of the sciatic nerve, when either the internal popliteal or the external popliteal segment of the sciatic appeared intact. At this level one is dealing rather with two nerves than with one, although with a more intimate anatomical relationship than below the point of bifurcation. But partial resection as implying reconstruction of individual fasciculi is a much more delicate procedure. In Ney's experience this operation was not unusual.[8] Each fasciculus was tested with the electrode; those that failed to respond were resected and coaptation effected with endoneural sutures.

It was universally acknowledged that a nerve bed free from scar tissue must be provided at the line of suture. Transposition to an adjacent intra-

muscular plane or in the absence of this, to the plane of the subcutaneous tissue, was a common practice.

The protection of the line of suture with any foreign tissue was generally condemned. This applied to fascia lata, to veins or to Cargile membrane. Of the methods of bridging defects there seems to be no difference between those adopted by the surgeons of the United States and by those of other countries. Primary nerve stretching, nerve transposition, as with the median, ulnar and musculospiral nerves, and the two-stage operation were the selected methods, in the order mentioned. Implantation and reconstruction by anastomosis were regarded as illogical. The two-stage operation virtually eliminated the necessity for transplants and succeeded when the transplant failed. The writer employed resection of bone but once. It is too formidable to be considered as an acceptable procedure except, perhaps, in cases of musculospiral paralysis with an ununited fracture of the humerus.

Of the important factors in the technique of nerve suture the avoidance of nerve distortion has been given the most prominence. It has been assumed that a sensory fasciculus can not function as a motor and vice versa. But it is difficult to determine or to prove just what influence nerve distortion may have. In some cases after suture of the musculospiral nerve there was almost complete absence of formication in the radial nerve, predominantly sensory in function, and intense formication in the posterior interosseous, a predominantly motor nerve.[8]

There are divergent views as to the maintenance of a definite nerve topography from the plexus above the level at which the muscular branches are given off. Some observers, including Stoffel,[9] Marie,[10] and more recently Kraus and Ingham,[11] maintained that the course of a motor fasciculus is straight from the point where the nerve has been made up to the point of offset of the fasciculus as a branch. In opposition to this view may be cited the experiments of Dustin[12] and McKinley,[13] each independently finding vast plexuses in the constituent elements of a nerve trunk with a continuous exchange of fibers from the parent plexus above to the point where the peripheral branches are given off. These findings, true as they may be, do not negative the importance of avoiding distortion, since while there may be free interchange of fibers between the nerve supply of certain muscle groups, as for example between the fasciculi of the anterior tibial and peroneal nerves in the sciatic trunk, the writer believes there is a more or less constant topography of the motor and sensory fasciculi in a given trunk, and after all, it is in the nerves of mixed function especially, such as the median and ulnar, that the maintainence of the proper axial relationship of the central and peripheral segments is important.

RESULTS

The following analysis was based in part on 3,129 peripheral nerve registers, representing the records of between 80 and 90 per cent of the neurosurgical operations performed prior to the discharge of the patients from the Army or the transfer of their supervision to the United States Public Health Service, under the War Risk Insurance,[5] and, subsequently, to the Veterans' Bureau.[6] Information concerning some of the peripheral nerve injuries included herein

was obtained by means of questionnaires issued through the Veterans' Bureau; from the published records of individual surgeons; from private communications from individual surgeons to the writer.

As stated above, between 80 and 90 per cent of the operations for the repair of nerve injuries were performed while the men concerned still were under control of the Army, under conditions considered quite ideal. These operations almost without exception were performed by skilled neurosurgeons who had trained personnel as assistants. Until his discharge from hospital, whether operated upon or not, the patient had the advantage of such auxiliary and supplemental measures as were provided by well-equipped physiotherapy departments. From date of discharge (the majority by October, 1919) systematic treatment ceased and organized supervision for the most part was discontinued.

For purposes of determining what the results of operative treatment were, only certain nerves were selected, because the injuries to them were in sufficiently large numbers to warrant conclusions concerning them. These nerves are shown in Table 10. Also, because combined lesions would cloud the issue, such lesions are omitted from consideration.

TABLE 10.—*Certain operated cases, observed in the peripheral nerve centers*

Nerve	Total	Operated	
		Number	Per cent
Brachial plexus	132	20	15.1
Musculospiral	516	228	44.1
Median	269	111	41.2
Ulnar	492	252	51.2
Sciatic	551	307	55.7
External popliteal	395	157	39.7
Internal popliteal	35	10	28.5
	2,390	1,088	

Of these 2,390 cases, 1,085 were operated upon and 1,305 unoperated. At first, 25 to 30 per cent was regarded as a conservative estimate of the proportion of cases in which operation would be required. Continued experience and observation proved this estimate too conservative as the figures just quoted indicate, 1,085 operated and 1,305 unoperated, in the ratio of 45 to 55 per cent. Since the cases under consideration do not include the operations performed subsequent to 1919, it is highly probable that such subsequent operations would equalize the proportion of operated and unoperated cases.

It should be understood that the examinations from which these end results have been compiled were not made by the officers stationed in the peripheral nerve centers. Because the patients were transferred to the care of the Veterans' Bureau, it was necessary to rely on the statements of physicians assigned to the various districts of that bureau through the country. It was impossible to secure through this source a detailed record by those familiar with the technique of peripheral nerve examinations and in the questionnaire distributed to the districts the officers were requested to record the results in terms of "good," "mediocre," and "negative."

NEUROLYSIS

With the exception of the brachial plexus and the internal popliteal, the proportion of neurorrhaphies to neurolyses was fairly uniform, varying from 65 to 75 per cent for the one and 22 to 34 per cent for the other. In round figures about three-fourths of the cases required resection and suture and the remaining quarter the conservative procedure. In the earlier stages of the reconstruction period surgeons were inclined to adopt the more conservative policy, but with a larger experience and the observation of many failures following neurolysis, a more radical policy prevailed.

TABLE 11.—*Proportion of neurorrhaphies to neurolyses*

Nerve	Neurorrhaphy	Neurolysis
	Per cent	*Per cent*
Brachial plexus	36	63
Musculospiral	72	22
Median	65	34
Ulnar	71	26
Sciatic	66	32
External popliteal	76	22
Internal popliteal	50	50

In estimating the merits of operations upon peripheral nerves the most convincing figures are those for the negative results, which represent failures. It is well known in the field of peripheral nerve surgery that perfect recoveries are only exceptionally obtained and the difficulty in defining sharply the grades of "good" and "mediocre" is manifest. Hence for purposes of contrast one should compare the cases which were outstanding failures and those in which there was a measure of success.

TABLE 12.—*The percentage of good, mediocre, and negative results after neurolysis.*[a] *Indirect observation*

Nerve	Good	Mediocre	Negative
Brachial plexus	0	66	33
Musculospiral	25	37	37
Median	7	71	21
Ulnar	10	64	25
Sciatic	8	63	28
External popliteal	0	53	46
Internal popliteal	0	50	50

[a] Source of information, Veterans' Bureau.

That the results following neurolysis were not as good as was anticipated may be attributed to insufficient knowledge of the pathology before or at the time of the operation. External neurolysis, or neurolysis proper, was regarded as appropriate in the compression syndromes when the essential lesion was the embedding of the nerve in perineural scar tissue. Assuming that the fasciculi were intact, that there were no intrafascicular adhesions, no interstitial cicatrices, one wonders how much neurolysis proper may have influenced the results. Would there not have been spontaneous regeneration in many of the cases whether neurolysis had been performed or not?

Endoneurolysis is an entirely different procedure and was used to advantage in a certain number of cases when there was evidence of an intraneural lesion. A free incision was made through the sheath when the latter was fibrosed; if the fasciculi were bound together with adhesions these were separated. But if the nerve was the seat of a frank interstitial neuritis, resection was considered essential.

The compilation of the end results in neurorrhaphy (Table 13) were based on a series of 400 cases. As previously stated, the examinations, upon which these figures are based, were not the personal examinations of the writer or of the operator, but were made by a number of physicians, not necessarily neurosurgeons, employed in the Veterans' Bureau. Hence the results must be considered approximate.

TABLE 13.—*The percentage of good, mediocre, and negative results in motor function after neurorrhaphy*[b]. *Indirect observation*

Nerve	Good	Mediocre	Negative
Brachial plexus	0	100	0
Musculospiral	11	66	22
Median	12	56	32
Ulnar	5	72	22
Sciatic	1	60	38
External popliteal	0	50	50
Internal popliteal	0	50	50

[b] Information secured through Veterans' Bureau.

Compared with the statistics from other sources, the end results, again measured chiefly in terms of failures, do not vary very widely, except in the case of the external popliteal nerve; the percentage of negative results is unaccountably high.

TABLE 14.—*The percentage of good, mediocre, and negative results in motor function in the total series of operated cases, including neurorrhaphy and neurolysis.*[c] *Indirect observation*

Nerve	Good	Mediocre	Negative
Brachial plexus	6	83	16
Musculospiral	18	51	30
Median	9	64	26
Ulnar	8	68	23
Sciatic	5	61	33
External popliteal	0	51	48
Internal popliteal	0	50	50

[c] Information secured from Veterans' Bureau.

In addition to these 400 cases of neurorrhaphies and 119 neurolyses, considered in Tables 11 to 14, a table of 497 operated cases (Table 15) including 132 neurolyses, 350 neurorrhaphies and 14 transplants, is given for comparison. This table is of greater value since the examinations were made mostly by an individual surgeon experienced in this particular field.

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TABLE 15.—*Percentage of end results of 497 operations, including 132 neurolyses, 350 neurorrhapies, and 14 transplants*[a]

Nerve	Good	Mediocre	Negative
Brachial plexus	33	37	29
Musculospiral	23	30	46
Median	58	28	14
Ulnar	12	55	31
Sciatic	25	41	33
External popliteal	31	52	16
Internal popliteal	46	46	8

[a] Compare with Tables 14 and 16.

The best results were obtained in the internal popliteal and median nerves with a failure in only 8 and 14 per cent respectively and "good" or "mediocre" results in 92 and 86 per cent respectively. The largest percentage of failures, as expected, was in the operations on the musculospiral nerve with failure in almost 50 per cent. The ulnar and sciatic nerves occupy an intermediate position with results not far apart, approximately 30 per cent failures and 70 per cent "good" or "mediocre."

The results en masse in the 470 operations yielded 34 per cent "good" results, 36 per cent "mediocre" and 26 per cent "failures." In other words in any large series of cases we may anticipate good or mediocre return of function results in two-thirds of cases, negative results in one-third.

TABLE 16.—*Percentage representing Tables 14 and 15 combined*

Nerve	Good	Medoicre	Negative
Brachial plexus	6	69	24
Musculospiral	38	39	22
Median	21	50	28
Ulnar	15	49	35
Sciatic	15	51	33
External popliteal	23	49	28
Internal popliteal	15	51	33

Comparison of statistics in peripheral nerve surgery is a questionable practice. The matter of interpretation of the words "good" and "mediocre" is a question in point. What one individual might record "good," the other might consider "mediocre." Therefore allowances must be made for the source of information—whether obtained by direct personal examination of the operator or indirectly through a physician unskilled in these very technical examinations, or perhaps from the patient himself.

No matter with what infinite care and with what nicety of approximation a nerve suture may be effected the percentage of successes and failures will depend upon the regenerating forces of nature. One can never tell what changes may have taken place in the spinal cells. It is with relation to the activity of the spinal cells that the time element becomes an influential factor. This factor, together with the degree of degeneration of the peripheral segment and the degree of atrophy or fibrosis of the muscles involved, must in many instances determine the end result.

TRANSPLANTS

In 17 experiments conducted by Huber[14] a defect of 3 cm. was successfully bridged by an autotransplant, and in 6 experiments a homotransplant was used with evidence which justified the indorsement. He was successful not only with fresh homotransplant but also with those stored in 50 per cent alcohol for 40 days. These brilliant results in the experimental laboratory in the use of the transplant, as a means of repairing defects, are in striking contrast to the reports from the peripheral nerve centers.

In approximately 1,414 operations upon the peripheral nerves in the Army hospitals there were in the neighborhood of 60 transplants used to repair defects. Of this number the writer has been unable to find the record of any "successful" result, except in a few isolated instances. In one "very marked improvement" is recorded after the use of three strands of a cutaneous nerve to repair a defect 6 cm. long in the musculospiral nerve; in another, "considerable improvement after one year" is recorded in a defect of 4 cm. in the external popliteal nerve, to repair which strands of a cutaneous nerve were used. In one instance the employment of an autotransplant to repair a defect in the ulnar nerve at the wrist was followed by definite contraction of the zone of anesthesia. One neurosurgeon reported that in 14 attempts there was but 1 case of transplant in the median nerve where, after four years, the patient's only sensation was a sense of tingling in the median distribution. That there is little need for the use of transplants to repair defects may be gathered from the experience of individual operators. In one series of 196 operations an autotransplant was used only three times. In another of 570 operations an autotransplant was used six times and homotransplant eight times. Considering the total number of cases and the results as recorded, the employment of the transplant either "auto" or "homo" as a practical method of bridging defects in peripheral nerves has proven a dismal failure in the hands of the surgeons of our country. The results of nerve stretching in a two-stage operation for the correction of large defects, even when a nerve is sutured under great tension, greatly surpass these obtained from the use of the transplant.

Why the results in the experimental laboratory can not be reproduced in human surgery has never been explained. To be sure, there are physical factors in the pathology of peripheral nerve lesions of the human that are wanting in the experimental animal, and what is of no small moment, the length of the graft employed in the experimental laboratory is only one-fourth or one-half of that required to repair the defect in the resections of extensive peripheral nerve lesions. Just as the transplant has proved successful in the laboratory, so has lateral implantation of the peripheral and central segments into an adjacent nerve, but so far as the writer is aware, neither the nerve flap operation nor nerve crossing or implantation has been applied successfully in the reconstruction of peripheral nerve injuries. Both operations seem illogical, and neither has found favor with those who, in dealing with hundreds of cases, have acquired an intimate knowledge of the problems involved.

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CHAPTER XIII

EXPERIMENTAL OBSERVATIONS ON PERIPHERAL NERVE REPAIR [a]

INTRODUCTION

In no field of medicine, perhaps, is the interdependence of experimental and clinical work so clearly demonstrated as in peripheral nerve surgery.

Questions which concern the structure, development, growth, degeneration, and regeneration, after injury, of the peripheral nerves have engaged the attention of observers for more than a century, and there exists an extensive literature, dealing with these and relative problems, to which both the experimenter and the clinician have contributed. A study of this literature, while showing constant advance in knowledge, as concerns all phases of the questions involved, will reveal also wide and fundamental divergence of opinions which have influenced and retarded progress as regards structural interpretations and their clinical applications.

The nervous system consists of independent, anatomic units, the neurons, related to each other by contiguity and not by continuity. The peripheral nervous system is, therefore, both on anatomic and functional considerations, a part of the central nervous system, and in its surgical treatment should be regarded as such. There are 31 pairs of spinal nerves, quite symmetrically arranged, which course singly or join to form plexuses and which throughout the thoracic and upper lumbar regions and for certain sacral nerves are connected with the ganglia of the sympathetic system through the white rami or preganglionic branches. Considered structurally, each spinal nerve consists of bundles of nerve fibers, certain of which are processes of neurons, known as neuraxes or axons, the cell bodies of which are situated in the ventral gray of the central nervous system or in the sympathetic ganglia and carry nerve impulses from the central nervous system to the periphery, and are thus known as efferent nerve fibers, while other nerve fibers are processes of neurons known as dendrites, the cell bodies of which are found in the spinal ganglia and conduct nerve impulses toward the central nervous system and constitute the neuraxes of afferent nerve fibers. The neuraxes and neuraxes dendrites, forming the nerve fibers of the spinal nerve, may be ensheathed in a layer of myelin, known as myelinated or medullated nerve fibers, or they may be naked, and are then known as nonmyelinated or nonmedullated nerve fibers. Considered functionally, we recognize in each spinal nerve nerve fibers belonging to one of four

[a] Report of the work of the Neurosurgical Laboratory, Department of Anatomy, University of Michigan, Ann Arbor, Mich. The following medical officers, on special assignments, collaborated in the experimental work for stated periods: Lieut. Col. Dean Lewis, Maj. J. F. Corbitt, Maj. Byron Stookey, and Maj. T. Roberg. During the latter portion of this investigation technical laboratory assistance was made available through a grant received from the committee on research of the American Medical Association, for which acknowledgment is here made.

functional systems, designating a functional system "as the sum of all the neurons in the body which possesses certain physiological and anatomical characters in common so that they may react in a common mode." [1] The functional systems of the spinal nerves are designated: 1, Somatic efferent; 2, visceral efferent; 3, somatic afferent; 4, visceral afferent. The nerve fiber composition of a spinal nerve may be represented graphically as shown in Figure 211.

FIG. 211.—Diagrammatic cross-section of the spinal cord, showing on the right side the nerve roots and type nerve fibers. A, Somatic efferent neuron; B, preganglionic neuron of the visceral efferent system; C, postganglionic neuron of the visceral efferent system; D, somatic afferent neuron; D′, somatic afferent neuron with nonmedullated processes; E, visceral afferent neuron (interoceptive impulses); PR. G., preganglionic bundle or white ramus; PO. G., postganglionic bundle or gray ramus; SY. G., sympathetic ganglion of the sympathetic chain

The somatic efferent fibers (fig. 211–A) are the neuraxes of neurons the cell bodies of which are located in the ventral portion of the spinal gray. They leave the cord through the ventral roots and terminate in skeletal muscle in sublammellar end plates or motor nerve endings. The nerve fibers belonging to this functional system are relatively large, myelinated fibers.

The visceral efferent fibers (figs. 211–B and C), or the sympathetic fibers of the spinal nerves, are neuraxes of sympathetic neurons, the cell bodies of which are situated in the sympathetic ganglia of the sympathetic trunks. They constitute the postganglionic nerve fibers. They enter the spinal nerves through

the gray rami communicantes, each spinal nerve having such connection with the sympathetic trunks. The sympathetic ganglion cells of the sympathetic trunks are in synaptic relation with the preganglionic neurons, the cell bodies of which are situated in the visceral efferent column of the spinal gray, their neuraxes leaving the spinal cord by way of the ventral roots of the successive thoracic and four upper lumbar nerves and by way of the white rami, branches reaching the sympathetic ganglia where they form synaptic relations with the sympathetic nerve cells, it being well known, through the fundamental experimental researches of Langley, that there are always two neurons concerned in carrying an impulse from the central nervous system, through the spinal nerves to involuntary muscle and glandular tissue. The investigations of Boeke make it probable that the visceral efferent fibers may play a part in the innervation of certain skeletal muscle fibers.

The somatic afferent fibers (figs. 211–D and D′) of the spinal nerves are the dendritic branches of sensory neurons, the cell bodies of which are situated in the spinal ganglia and convey impulses from the periphery to the central nervous system. A certain per cent of these nerve fibers are relatively large myelinated fibers, which have origin in peripheral nerve endings, both encapsuled and nonencapsuled. They are connected with the larger and more complex ganglion cells. A certain per cent of somatic afferent nerve fibers are nonmyelinated (Ranson) or are very fine myelinated fibers (Langley) which are connected with the smaller and simpler ganglion cells of the spinal ganglia. They are distributed in large part to the skin but also to the muscular branches.

The visceral afferent fibers (fig. 211–E), strictly speaking, are not primarily distributed to the peripheral nerves of the body wall and extremities, but to the thoracic and abdominal viscera which they reach by way of the white rami. The cell bodies of these fibers are in the spinal ganglia, their neuraxes pass through the respective dorsal roots to the dorsal column of the spinal cord.

According to function, the somatic afferent neurons are classified either as exteroceptive fibers, which carry impulses from sense organs and from the surface of the body, or as proprioceptive fibers, carrying impulses arising from within the body, from joint, tendon, and deep connective tissue and from muscular tissue, and also from the semicircular apparatus of the ears. The visceral afferent nerve fibers are said to carry interoceptive nerve impulses. There is no recognizable structural differentiation in afferent nerve fibers to be correlated with the type of impulses carried, though each group of afferent fibers is connected with special receptors or sensory nerve endings in the periphery and with distinctive neuron paths in the central nervous system. The cranial nerves, structurally considered, are very similar to the spinal nerves, but collectively considered contain additional functional systems having restricted distribution and specialized function; considerations which need not receive special discussion here.

STRUCTURE OF A NERVE

The efferent and afferent fibers of a nerve trunk are intermingled and run together in small bundles known as funiculi. A funiculus may approach a millimeter in size. Each funiculus is surrounded by a connective tissue sheath known as the perineurium, composed of several lamellæ of flattened collagenous

connective tissue bundles; anastomosing here and there, between these flattened connective bundles, spread out fibroblasts are found which, on the inner surface of the perineurium, form a fairly distinct layer. The writer has not been able to demonstrate the fairly definite layer of endothelioid cells described by Key and Retzius. A few wandering cells and a few clasmatocytes are found between the lamellæ of the perineurium. Relatively few elastic fibers, arranged in network, are found in the perineurium. Flattened trabeculæ of collagenous connective tissue pass from the perineural sheaths to the interior of the funiculi and there is found a loose connective tissue, consisting of fibrils and fine fibers of collagenous connective tissue and a few elastic fibrils, disposed as a network and found between the fibers or small bundles of such, and forming more or less distinct tubular sheaths for the fibers of the funiculi. This constitutes the endoneurium of the funiculus. In it are found a few fibroblasts and a few clasmatocytes and wandering cells. The spinal nerves generally consist of more than one funiculus, and certain of the larger ones have many funiculi. Surrounding the whole nerve trunk and extending between the funiculi, there is found an areolar connective tissue, continuous with the surrounding connective tissue, which is known as epineurium. The name would suggest that this sheath is upon the nerve. It should be understood that the epineurium extends between and surrounds the several funiculi of a nerve trunk; therefore, an epineurial stitch or suture may pass through a nerve trunk, conceivably between the funiculi. The epineurium consists of looser and denser areolar connective tissue with often, especially in the larger nerves, an appreciable amount of adipose tissue, disposed in small groups of fat cells or in scattered cells. In the epineurium are found the larger blood vessels and the lymph vessels of a nerve trunk, also sensory nerve endings for the nerve itself. The cells of the epineurium are largely of the type of the fixed fibroblasts; wandering cells and clasmatocytes are also found, but in variable numbers; mast cells have been described. The details of the ultimate distribution of the blood and lymph vessels of a nerve trunk require further study and should be given special consideration for each of the several larger nerve trunks, subject to injury. The larger blood vessels, both arteries and veins, course in the epineurium. Terminal arterioles pass through the perineural sheaths of the several funiculi and break up into capillaries which course in the endoneurium, between the nerve fibers, forming long-meshed anastomoses. The capillaries of the funiculi are relatively scanty. Definite lymph vessels and lymph capillaries have not been shown to exist within the funiculi and perineural sheath. They have been demonstrated by injection in the epineural sheath.

Special interest was drawn to the funicular structure of peripheral nerves through the studies and publications of Stoffel[2] and his followers, who claimed that the several peripheral nerves presented a definite funicular morphology which extended throughout the nerve trunk and was fairly constant, so that definite sensory and motor paths could be demarked in the internal topography of the nerve. This laboratory was not especially concerned with this problem, realizing that during healing or regeneration of a cut nerve, in the field of the scar, even with the best of suture, the funicular pattern is to a large extent lost. Extended researches bearing on this problem were undertaken by Heinemann,[3]

Borchardt and Wyasmenski,[4] Langley and Hashimoto,[5] Compton,[6] Dustin,[7] and Kunzel.[8] These observers have shown, either by careful dissections of macerated nerve trunks, or by means of carefully oriented serial sections of nerve trunks, that Stoffel's views can not be maintained. It has been shown that an extensive anastomosis and exchange of nerve fiber bundles exists between funiculi and that the funicular pattern is not the same even at relatively short intervals and not necessarily alike in the same anatomic nerve in different individuals. This question has been well summarized by Stookey,[9] who has reviewed the pertinent literature.

STRUCTURE OF NERVE FIBERS

Nerve fibers are either myelinated—medullated, or nonmyelinated—nonmedullated. A myelinated nerve fiber consists of the neuraxis or axon, the myelin or the medullary sheath, and the neurolemma with its neurolemma nuclei or sheath cells. The neuraxis is the direct continuation of the respective nerve cell or neuron, the essential and conducting part of a nerve fiber, and passes uninterruptedly from the cell body to its destination. It must be regarded as in protoplasmic continuity with the cell body of the neuron, its trophic center. The neuraxis is devoid of any sheath in the immediate vicinity of the nerve cell and very generally loses all sheaths before termination. It consists of neurofibrils, continuous with the neurofibrils of the cell body of the peripheral neuron, embedded in a homogeneous neuroplasm. A delicate, peripheral protoplasmic sheath may be present, known as the axolemma, but this is difficult to establish conclusively. The myelin sheath in the living and structurally unaltered nerve fibers appears as a homogeneous and structureless sheath which is interrupted from place to place at stated intervals, at the nodes or constrictions of Ranvier. These nodes occur at regular intervals of a length approximately one hundred times the diameter of the fiber. The segment of a nerve intervening between two nodes is known as an internodal segment. The structure of the myelin has not been fully determined, nor is it clear whether the myelin layer is to be regarded as a part of the neuron or as a special sheath quite distinct from the neuraxis. The myelin sheath presents quite distinctive structural appearances depending on the mode of fixation and staining of the nerve fibers. In segments of the same nerve, treated with different reagents in fixation and staining, quite dissimilar pictures of myelin structure may be obtained. It would seem that from the complex material which forms the myelin, largely made up of lecithin, there separates out a coagulable substance which under certain treatment forms a reticulum, keratin-like in nature, and known as the neurokeratin net, the arrangement of which varies with different fixations. The majority of the special structural characteristics described for myelin are regarded as fixation artifacts. It is stained black in osmic acid and is differentially stainable by a variety of methods. It presents special manifestations in degenerating nerves. In early stages of development of nerve fibers or in early stages of regeneration of peripheral nerves, the myelin seems to appear as a continuous, delicate sheath, a differentiation of the peripheral part of the neuraxis; in further development the nodes of Ranvier appear. There is at hand evidence, though not conclusive, to

warrant considering the myelin sheath as a part of the respective neuron. The suggestion that the myelin is in its histogenesis closely related to the neurolemmal sheath is not without its supporters. In a comprehensive histologic and histopathologic study of peripheral nerves by Doinikow,[10] in which extended consideration is given to the structure of the myelin sheath, the conclusion is reached that the plasma cells of Schwann consist of a denser nuclear zone and a looser meshwork which pervades the myelin sheath of the entire internodal segment, in the meshes of which is contained myelin substance. Not unlike this conclusion is that of Nemiloff,[11] who regards the nuclei of the neurolemma sheath as related to a protoplasmic reticulum which pervades the myelin sheath. According to these observations, the myelin sheath is not a part of the neuron but an ensheathing structure. The neurolemma forms the outermost layer of the myelinated nerve fiber of peripheral nerves. It is a very thin, apparently homogeneous layer closely applied to the myelin sheath. There is at hand evidence of a delicate fibrillar structure of the neurolemmal sheath. The flattened, oval nuclei found lying on the inner surface of the neurolemmal sheath, one for each internodal segment, are considered as part of the neurolemmal sheath and are known as neurolemmal cells or sheath cells. Histogenetically considered, they are of ectodermal origin. It has not been possible to obtain conclusive evidence as to whether the neurolemma forms a continuous sheath or is interrupted and cemented end to end at the nodes of Ranvier. In degenerating nerve fibers the neurolemmal sheaths form a delicate tubular structure which does not fragment with the neuraxis and myelin and the sheath cells proliferate and separate from its inner surface. The neurolemma sheath is absent from nerve fibers of central nervous system; its place is there very probably taken by the neuroglia tissue. A nonmedullated fiber consists of a neuraxis which is made up of neurofibrils and neuroplasm with a delicate outer protoplasmic layer or axolemma. They present nuclei at relatively frequent intervals; nuclei which have the appearance of neurolemma or sheath nuclei, although it is difficult to demonstrate clearly a definite neurolemmal sheath. It is quite possible that in the nonmedullated fibers the sheath cells do not form a continuous neurolemmal sheath.

DEVELOPMENT OF PERIPHERAL NERVE FIBERS

Since histogenesis and experimental embryology of the nervous system has done much to clarify the problems of degeneration and regeneration of peripheral nerves, a brief consideration may here be given to the question of development of peripheral nerves. It is now generally believed that the nerve fibers of the entire nervous system are derived from the neurosensory ectoderm through the neuroblasts; the afferent fibers and the visceral or sympathetic efferent fibers largely from the neural crest, the anlage of the spinal and indirectly of the sympathetic ganglia; the somatic efferent fibers from the neural tube. The "outgrowth theory" of nerve developments first formulated by His [12] is now very generally accepted. According to this theory the neuraxis (and the dendrites) of a neuron are regarded as the outgrowth from a single cell, the neuroblast, no matter what the length of these processes. The growing tip of the neuraxis shows an expansion, known as the end-disc or the in-

cremental cone; this is thought to have ameboid properties. The theory of His does not admit of demonstration in adult tissue, but admits of "near proof" in early embryonic stages, especially in tissues stained in differential neuron stains. Harrison's[13] experimental observations of growing in coagulated lymph ganglion cells from the spinal cord of amphibian embryos, in which growing and budding neuraxes could be observed under the microscope, very substantially confirmed the outgrowth theory of nerve development. Growing neuraxes of the ventral and dorsal roots of suitably early embryonic stages are from the beginning accompanied by cellular elements which are in very close apposition with the growing nerve fibers. These cells, which were regarded as of mesodermal origin by earlier observers, are now known to be of ectodermal origin and are variously thought of as contributing to the formation of sheath cells or as participating in the formation of the neuraxis itself. The constant presence of these sheath cells in the early stages of growing nerve roots led to the formulation of the "chain theory" of peripheral nerve development, according to which, in essential, each internodal segment is thought to be derived from a cell, the neurons thus constituting a colony of cells in chain, or a syncytium. With this theory the names of Balfour,[14] Dohrn,[15] and Bethe,[16] are especially associated. Modifications and interpretation of these two theories of peripheral nerve origin and growth are extant. Hensen[17] early contended for a primary connection between the nerve cells and the muscular and other tissues and thought that out of this primary syncytial net the nerve fibers were developed. Held[18] has more recently amplified this view. Such questions are not determined by a study of sections alone, although such study has contributed largely to the solution of the problem; experimental embryology has been of material assistance. Harrison[19] was able to ablate the neural crest in very young amphibian embryos, thus removing the anlage of the dorsal spinal ganglia without injuring the ventral part of the spinal cord from which the ventral root fibers have origin. It was found on development of the ventral root fibers that these were devoid of sheath cells. Further experiments by the same observer and others, including limb transplantation in young amphibian embryos, which on attachment and outgrowth in new positions became neurotized, indicate that there does not exist a primary connection between nerve cells and the peripheral tissues, a sine qua non to nerve growth. Observations made and deductions drawn from experimental embryology bearing on peripheral nerve development have been summarized as follows by Streeter:[20] "It was shown that no peripheral nerve fibers would develop in an embryo from which the nerve center had been removed, thus establishing the fact that the ganglion cells are an essential element of the fibers. It was shown that the sheath cells of Schwann, upon the influence of which in the formation of the fibers many histologists had placed much emphasis, were not essential to the growth of the nerve fiber, and that the axis cylinders will develop and extend out in the surrounding tissues in the normal way and reach their normal length in specimens where the sheath cells have been eliminated. It was shown by modifying the environment of the developing nerves that fibers will form in surroundings entirely different from their natural path and establish completely foreign connections." Histogenetic studies have shown quite

conclusively that the neuraxis is a protoplasmic outgrowth from a single neuroblast. The prevailing opinion is that the neurolemmal sheath and its sheath nuclei are of ectodermal origin, derived directly or indirectly from the neurosensory ectoderm, as also the capsule cells of spinal and sympathetic ganglia. These neurolemmal sheath cells, however, are not to be regarded as potential neuroblasts. There exists less certainty as to the development of the myelin sheath. This sheath seems a part of the neuraxis, which in its deposition is influenced by the sheath cells. Very careful studies of the histogenesis of the myelin are required before the structure of the myelin sheath and its relation to the neuraxis can be fully determined; in such studies experimental embryology must play its rôle.

DEGENERATION AND REGENERATION OF PERIPHERAL NERVES

There exists a very extensive literature dealing with the problem of peripheral nerve degeneration and regeneration, far too extensive to receive even cursory review here; certain main phases of the development may be noted and briefly considered, since such treatment will obviate repeated restatement in discussing the experimental work. Arnemann,[21] as early as 1787, recognized the fact that a severed nerve lost its conductivity, and Cruikshank [22] and Haighton [23] believed themselves to have demonstrated experimentally regeneration of a severed peripheral nerve. However, it was not until 1852 that Waller [24] clearly demonstrated that the portion of a nerve fiber separated from a "ganglion cell," when a nerve is severed, undergoes degeneration and is regenerated through down growth from the central part. Ranvier [25] and Vanlair [26] materially extended our knowledge more particularly as concerns the down growth of central fibers in regeneration. Their views were controverted by Schiff, Erb, and Wolberg, so that about 1890 there existed three main views concerning the mode of regeneration of severed peripheral nerves: 1, The view of Waller, that after degeneration of the peripheral stump regeneration was through down growth of neuraxes derived from the central stump; 2, that after secondary degeneration neuraxes developed in the peripheral stump which were secondarily united to the central fibers; 3, that the neuraxes of the peripheral stump did not degenerate. In the few years following 1890 there appeared a series of monographic contributions dealing with this problem: Büngner,[27] Howell and Huber,[28] Stroebe,[29] Huber.[30] Büngner, in his frequently quoted communication, paid especial attention to sheath-cell proliferation, and defined clearly the nucleated protoplasmic strands, derived from the proliferating sheath cells and designated by him as "bandfasern," which appear during the second and third week after injury, and were interpreted by him as new nerve fibers or potential nerve fibers. Stroebe, in his experimental studies, believes himself to have shown the down growth of neuraxes from the central stump. Huber, using Stroebe's method of neuraxis staining in an experimental study of bridging nerve defects, believed he had demonstrated the downgrowth of central neuraxes, the division of neuraxes in regeneration and the incremental cone at the growing ends of the neuraxes, the same as found on the growing tips of neuraxes in development, and in neurons grown in tissue cultures. These observations were followed by studies of Galeoti and Levi,[31] Kennedy,[32] and Wieting,[33] each

of whom favored the view of peripheral autoregeneration in degenerated nerve. At about 1900 two main and opposing views as to the regeneration of degenerated nerve were held: 1, What is known as the monogenetic conception of nerve regeneration, according to which regeneration of a degenerated severed nerve is through downgrowth of neuraxes derived from the neuraxes of the nerve fibers of the central stump, at all times connected with central nerve cells; 2, a polygenetic conception, according to which regeneration is obtained through cells derived from both the central and peripheral stump. The technical staining methods then at the disposal of observers were inadequate to admit of clear and differential staining of neuraxes, leading often to differences in the interpretation of observations made. Bethe [16] hoped to bring solution to the problem through a series of especially devised experiments in which downgrowth of central fibers was thought to be obviated. Bethe believed he had demonstrated new nerve fibers in a distal stump completely separated from the central connection. The experiments of Bethe seemed conclusive, and received wide consideration; they were refuted by the experimental observations of Langley and Anderson,[34] Lugaro,[35] and others. Several lines of investigation in correlated fields did much to bring solution to the problem: The experimental embryonic observations of Harrison and others contributed largely to the confirmation of the neuron doctrine and the outgrowth theory of nerve development, as above stated; the histogenesis of neurons was much more carefully studied; marked improvement in technical histologic methods was effected, especially as concerns the silver precipitation methods of Golgi, Cajal, Bielschowski, and Ranson, and the intra vitam methylene blue method of Ehrlich. A series of experimental studies on nerve degenerations and regenerations was undertaken, controlled by careful histologic studies, in which the downgrowth of the neuraxis in regeneration could be followed step by step. This more recent literature includes contributions by Perroncito,[36] Poscharissky,[37] Cajal,[38] Ranson,[39] Boeke,[40] [41] Dustin,[42] Ingebrigsten,[43] and others, in all of which the modern silver precipitation methods for staining neuraxes have been used to control experimental results, the consensus of their work confirming the monogenetic or downgrowth theory of neuraxis development.

An injury to a peripheral nerve, producing severance of continuity induced by crush, sharp instrument, bullet wound or laceration, calls forth a series of structural changes in the distal segment, known as secondary degeneration or Wallerian degeneration, involving at about the same time the entire distal stump, except for a narrow zone in the immediate vicinity of the wound, a zone of traumatic injury the width of which rarely exceeds 0.5 cm. These structural changes are influenced by the presence or absence of the myelin and will be described separately for the two types of nerve fibers.

DEGENERATION OF MYELINATED NERVE FIBERS

For a period of three to four days in dog and man, two to three days in the rabbit and guinea pig, the nerve fibers distal to the line of injury, except in the zone of traumatism, show no demonstrable structural change and respond to mechanical and electrical stimulation. Structural change is first demonstrable in the neurofibrils of the neuraxis; they show varicosities and hypertrophy and

granular change (Mönkeberg and Bethe),[44] and in pyridine-silver preparations, irregularities of contour and staining (Ranson).[39] Beginning with the third or fourth day (man and dog; second or third day, rabbit and guinea pig) changes in the myelin sheaths in certain of the myelinated fibers is noted, consisting of irregularly placed enlargements and constrictions, followed by fragmentation or segmentation of the myelin and soon after of the neuraxis, resulting in the formation of segments, found within the continuous neurolemma sheath, known as myelin ellipsoids, presenting rounded ends inclosed by a layer of myelin and containing fragments of the neuraxis. This fragmentation of the myelin sheath and neuraxis is preceded or accompanied by the hypertrophy of the protoplasm of the sheath cells, their nuclei showing richer chromatin content. These, in their growth, first compress the myelin and neuraxis and, as these fragment, hypertrophy to occupy the lumen of the neurolemma sheath. These primary changes in the myelin and neuraxis are followed by progressive fragmentation of the myelin ellipsoids, resulting in the formation of larger or smaller masses of oval or spheric shape, many still containing fragments of the neuraxis differentially stainable with silver methods. This is accompanied by growth of the protoplasm of the sheath cells and proliferation of their nuclei in part at least by mitosis (Büngner,[27] Huber[45]). The hypertrophied protoplasm of the sheath cells begins to surround the myelin remaining. By the end of the first week after injury there are still to be found some few myelinated fibers which do not show fragmentation of the myelin; however, the majority of them show evidence of degeneration but to a variable degree. During the second week after injury there is noted a growth of the sheath cell protoplasm and a proliferation of their nuclei and a progressive fragmentation of the myelin remains. The sheath cells exert a phagocytic action on the myelin remains, so that during the second and third weeks after the injury the myelin globules become progressively less numerous and smaller and the protoplasm and nuclei of the sheath cells form distinct nucleated syncytial bands, still containing a variable number of myelin globules. The nucleated syncytial bands were first fully described by Büngner[27] as the "bandfasern" and, regarded as new nerve fibers, they were designated as "embryonic fibers" by Howell and Huber[28]. These syncytial, protoplasmic, nucleated bands, developed through hypertrophy of the sheath cells, constitute a stage in the degeneration of peripheral nerve fibers which extends through weeks and months. They represent an undifferentiated, perhaps embryonic, protoplasm, and are of ectodermal origin. Büngner[27] and Bethe[16] and other adherents of the school of polygenetic nerve regeneration, have described a delicate, longitudinal striation within the protoplasm of the "bandfasern," indicative of neurax is development and of peripheral autoregeneration. Faint longitudinal striation is now and again seen in the "bandfasern" in silver preparations, but transition stages between the syncytial protoplasmic bands and developed neuraxes have not been demonstrated. In considering regeneration of nerves it will be noted that neuraxes appear in the distal degenerated stump before the "bandfasern" are fully developed. The question of the mode of removal of the myelin in degenerating nerve fibers has received extensive consideration; both fixed and wandering cells of the

peripheral trunk and its vessels have been brought in causal relation with this process. Doinikow,[10] using various fixing and staining methods, has made a critical study of this question in degenerating nerves of the rabbit and finds that with the beginning of fragmentation of the myelin, fat droplets are found in the protoplasm of the sheath cells which are thought to pass to the tissue lymph spaces of the endoneurium probably in colloidal solution. The fourth day after injury, fat droplets are found in the endoneural cells and by the end of the first week in the cellular elements of the perineurium.

DEGENERATION OF THE NONMYELINATED FIBERS

The account here given is based on Ranson's [39] observations in preparations stained with pyridine-silver methods. Two types of nonmyelinated fibers are recognized; such as degenerated during the first week, thought to be afferent fibers; such as degenerated during the second week, thought to be visceral efferent fibers. Degeneration of the former begins soon after injury, the neuraxis becoming granular and during the second and third day showing alternate darker and lighter segments, the former representing neuraxis remains, the latter perhaps exudate. By the fourth day the darker segments disintegrate and disappear, so that by the end of the first week after injury the degenerated fibers are difficult to see. A proliferation of the sheath cells takes place and fine, nucleated protoplasmic bands develop and are found, usually, grouped in small bundles. The more slowly degenerating nonmyelinated fibers may present uniform staining nearly two weeks after injury and be mistaken for newly formed neuraxes; their mode of degeneration is the same as that of the more rapidly degenerating nonmyelinated fibers. "We have, therefore, as the terminal stage of the degeneration of the nonmedullated fibers, nucleated protoplasmic bands which differ from similar bands formed from the medullated fibers only in size and in absence of myelin droplets." (Ranson.)[39]

DEGENERATION OF NERVE ENDINGS

Tello [46] and Boeke [40] have used differential silver staining methods in the study of motor nerve endings in degeneration. The account of Boeke is here followed. This investigator found that changes are observed in the neurofibrillar net of the endplate during the first day after injury in that these fibrils stain only lightly. This stage lasts only a short time and is followed by one in which the fibrils hypertrophy and agglutinate and stain more deeply. This agglutination of the neurofibrils proceeds until darkly staining irregular strands are formed; these clump, run together, fragment and form irregular stainable masses which ultimately disappear. The telolemma nuclei are said to disappear and the sole plate nuclei to proliferate; the sole plate hypertrophies. The degeneration of the neuromuscular and neurotendinous and other proprioceptive nerve endings awaits special study with the use of modern differential neuraxis staining methods. It can be stated that the neuraxes disappear completely from the endings with the degeneration of peripheral nerves.

THE NEUROLEMMA SHEATH

The ultimate fate of the neurolemma sheath of degenerating peripheral nerve fibers has not been conclusively determined. As has been stated, during the early stages of degeneration, while the protoplasm of the sheath cells shows hypertrophy and their nuclei proliferation, the neurolemma sheath as such appears to show no structural changes. In cross or in longitudinal sections of the peripheral stump of a degenerating nerve, one to three months after the beginning of degeneration, it seems possible to differentiate membranous sheaths, surrounding the nucleated syncytial bands, quite evident in regions where myelin globules are still present, though it is not possible to stain the neurolemma sheaths differentially. In experimental observations on degenerate nerves, extending 12 to 15 months after injury to the nerve, what appear as collapsed neurolemma sheaths, surrounding nucleated protoplasmic bands, are thought to be present. According to the observations of Cajal, the neurolemma sheaths are said to disappear several weeks after the formation of the nucleated protoplasmic bands, these bands remaining surrounded by a fibrillar sheath of connective tissue origin, the fibrillar sheath of Retzius or of Henle. That a delicate sheath, either of ectodermal origin, neurolemma sheath, or of mesodermal origin, the fibrillar sheath of Retzius or of Henle, surrounds the nucleated, syncytial protoplasmic bands, the product of sheath cell proliferation, months after the degeneration of a peripheral nerve is under way, seems well established.

DEGENERATION IN THE PERIPHERAL AND CENTRAL ZONE OF TRAUMATISM

There are observed certain structural changes in the immediate vicinity of the wound, differing from the changes noted for secondary nerve degeneration, involving both myelinated and unmyelinated nerve fibers. In sections of an injured nerve trunk, including that portion of the distal stump adjacent to the wound, fixed in chrom-acetic-osmic mixture, about 24 hours after the injury, it will be observed that the myelin sheaths of the myelinated fibers do not stain black in osmic acid, as do the nerve fibers more distal, but present a granular appearance and indistinctive coloring. This appears to be the result of the traumatic injury. The neurolemma sheaths appear distended, leucocytes appear in appreciable numbers, both between and, now and again, within the neurolemma sheaths. These changes are noted near the wound at a time when 1 cm. distal, the nerve fibers show no structural change nor alteration in conductivity. In preparations of the distal stump of the wound region stained after differential neuraxis staining methods, Perroncito,[36] Cajal,[38], Ranson,[39] and others have noted, both for myelinated and nonmyelinated nerve, changes in the neuraxis regarded as an abortive autoregeneration, consisting of side branches terminating in bulbous ends. These may be observed in certain nonmedullated fibers by the end of the first day and may be quite numerous; they do not show much growth and the majority disappear within a few days. Certain of the myelinated nerve fibers show a similar phenomenon. The peripheral end of the central stump of a divided or injured nerve degenerates for a certain distance centrally; the distance varying with the type of injury, though it is usually not more than 0.5

cm. to 1 cm. The degenerative changes noted here are essentially the same as described for peripheral secondary nerve degeneration. Kirk and Lewis[47] believe that there is present an early hypertrophic reaction of the neurolemma sheaths adjacent to the line of section, first noticed as an increase in the protoplasm surrounding the sheath cell nuclei followed by mitosis of these nuclei, so that between the fourth and fifth day syncytial nucleated protoplasmic bands have developed. Ranson[39] has described certain changes in the nonmyelinated fibers of the central stump. An early abortive regeneration analogous to that described for similar fibers in the wound region of the distal stump was noted, the fine side branches terminating in end-discs which develop only slightly after their first appearance and disappear with the cellulipetal degeneration of nonmyelinated fibers, which begins about the third day after injury and extends about 2 cm. centralward, degenerating as do the nonmyelinated fibers of the distal stump. In preparations stained in differential neuraxis stains, certain neuraxis phenomena are observed in the myelinated fibers of the distal end of the central stump which are regarded as degenerative in character. In certain of these myelinated fibers, 0.2 mm. to 0.5 mm. from the wound, a zone of reaction is found in which the neuraxis is greatly increased in diameter, with neurofibrils staining more deeply and apparently hypertrophied, with increase in neuroplasm; distal to this zone of neuraxis reaction, in a respective fiber, the neuraxis disintegrates. Very early branching of the neuraxes in the immediate vicinity of the wound is noted. The newly formed branches may grow into the exudate of the wound, ending in small discs, or remain within the old neurolemma sheaths, where they become entangled and in further growth often form quite complex skeins. These phenomena appear to be abortive attempts at regenerative and are rather to be associated with degenerative processes.

REGENERATION OF PERIPHERAL NERVES

The process of regeneration of a peripheral nerve degenerated after injury, is initiated before the formation of the nucleated syncytial protoplasmic bands is well under way; a topical and timely separation of the two processes can not well be made since they are concurrent; they deserve separate discussion since they are independent. Certain of the main phases in the interpretation of the process of nerve regeneration were considered in the brief review of the literature preceding this section and it was noted that with the introduction of differential neuraxis staining methods and their use in experimental studies of nerve degeneration and regeneration that the downgrowth or monogenetic theory of neuraxis development has become quite generally accepted. The studies of Perroncito,[36] Cajal,[38] Ranson,[39] Boeke,[40,41] Kirk and Lewis,[47] Dustin,[42] Ingebritsen,[43] and others, all of whom have used these special silver methods to control the results of experimental observations, have been especially helpful in bringing clarity to this subject. Boeke, one of these more recent workers, in an excellent study expresses himself as follows: "I place myself without question as adopting the viewpoint that as in development of embryonic nerve fibers, the regenerating nerve fibers arise exclusively through outgrowth from divided nerves of the central stump, which enter the peripheral path and in

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this reach their peripheral destination." While unanimity has not been reached in all points there is quite general agreement that the down-growing neuraxes, derived from the central nerve fibers, are a sine qua non of the regeneration of the peripheral degenerated portion of a divided or injured nerve. These

FIG. 212.—Microphotograph of a pyridine-silver preparation from a longitudinal section of the distal end of the central stump of the sciatic of a dog, 11 days after the operation of cable-auto-nerve transplant, showing division of down-growing central neuraxes

more modern observations have extended but have confirmed fully conclusions reached by a group of observers, using less satisfactory methods and working nearly 25 years ago. One quotation may be permitted. Huber,[30] at the conclusion of an extended study on the repair of nerves after loss of sub-

stance, expresses himself as follows: "The regeneration of the peripheral end (which always degenerates so that only the old sheaths of Schwann containing a band of nucleated protoplasm, developed from the hyperthropied protoplasm and proliferated nuclei of its fibers, are met with) is the result of an outgrowth of new axis cylinders from undegenerated axes of the central stump, the budding axes following paths of least resistance."

Evidences of regeneration are noted in the distal end of the central stump of a divided nerve within the first day after injury (Perroncito [36] and others) in the form of fine branches derived from central neuraxes, which grow into the exudate of the wound or remain within the neurolemma sheaths. These

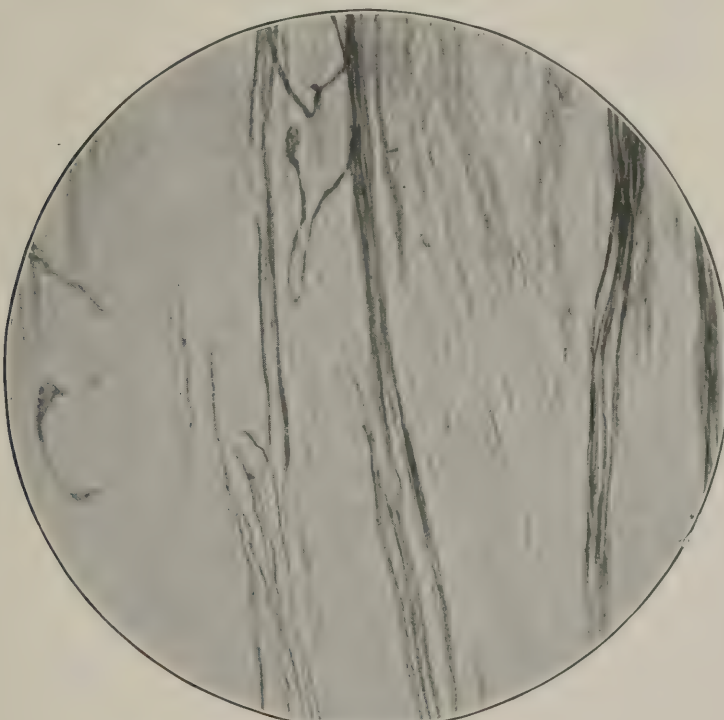

FIG. 213.—From longitudinal section of a regenerating distal segment of a severed nerve several weeks after operation. Note the single neuraxis deflected upon itself and terminating in a prominent end-disc or incremental cone. Pyridine-silver preparation

early branches of the central neuraxes, very likely, in part degenerate again; at least there is not marked progress until toward the end of the first week after injury, evinced now by numerous side branches and end divisions of central neuraxes, usually several tenths of millimeters central to the cut ends of the fibers. The central neuraxis of a myelinated fiber may here give off numerous new branches, the number estimated as high as 50 by Ranson,[39] clearly evident in cross sections of suitable stages in which, in the crosscut regenerating fibers of the central stump, a variable though appreciable number of new neuraxes may be found within one neurolemma sheath, often found arranged in a circle surrounding the old neuraxis of the respective fiber. These newly formed

neuraxes grow toward the periphery of the central stump, within the old neurolemma sheaths, having a more or less parallel course, or for reasons not satisfactorily explained may assume a very complex coiled or spiral arrangement, forming longer or shorter skeins which were first clearly defined by

FIG. 214.—Taken from the distal half of a neuroma, 21 days after severance of the sciatic nerve of a dog; pyridine-silver preparation. The figure presents a number of spiral formations (Perroncito spirals), several end-discs or incremental cones, the ends of down-growing neuraxes, crisscrossing of down-growing neuraxes, typical of their growth through embryonic connective tissue

Perroncito [36] and are often referred to as the spirals of Perroncito. On the ends of the down-growing neuraxes smaller or larger end-discs or incremental cones, similar to those found on developing, embryonic nerve fibers are easily demonstrated. They often are directed toward the periphery but are also

found directed centralward and are conspicuous in the Perroncito spirals. The end-discs on the neuraxes are often many times the diameter of the respective neuraxis, and it is conjectured that their relative size is proportionate to the resistance met with by the downgrowing neuraxis. The nonmedullated fibers of the central stump begin regeneration about the fourteenth day after injury; these downgrowing neuraxes having small end-discs and are often found arranged in small compact bundles. The downgrowing branches of the neuraxes of both the myelinated and the nonmyelinated nerve fibers of the central stump are first nonmyelinated. The very marked increase in the number of the central neuraxes was not appreciated until these fine nonmedullated nerve fibers were brought to view with silver staining, the evidence contributing largely to the substantiation of the theory of the downgrowth of central neuraxes in the regeneration of a peripheral degenerated nerve. From the beginning of the time of budding and downgrowth of central neuraxes, certain of them reach the exudate of the central wound; their number is appreciable toward the end of the first week after injury. As the down-growing neuraxes reach the exudate and the organizing embryonic connective tissue of the wound region, whether suture has taken place or not, the small bundles of downgrowing neuraxes lose their regular arrangement and direction parallel to the long axis of the nerve and assume an irregular crisscross course and either as single fibers or small bundles of such they course through the wound region. Immediate suture of a severed nerve does not seem to accentuate the rate of downgrowth of the central neuraxes, nor is the forming scar tissue of the wound region negligible, even under the most favorable suture conditions, in influencing the downgrowing neuraxes and in dispersing them sufficiently to influence the funicular structure. Now and again central neuraxes may be traced through several divisions in the same or successive sections passing through the wound region. Neuraxes terminating in end-discs within the organizing scar tissue of the wound after suture or in the central stump when no suture has taken place, are to be observed in nearly every section in suitably stained sections of requisite stages; they are found extending in every direction. In cross and longitudinal serial sections of the wound region, including approximately one centimeter of the distal and central stumps adjacent to the wound, and taken at intervals of three to five days during the first three weeks after severance or injury of the nerve, and prepared after the differential silver neuraxis staining methods, a progressive neurotization of the scar tissue may be observed, proceeding from the center to the periphery, and easily demonstrated in the region at a time when no neuraxes are found in the more distal segments of the degenerated nerve. There is noted a gradual decrease in the number of neuraxes as one passes from the more central to the more distal portion of the wound. In cases of primary suture of a severed nerve, new neuraxes of central origin are found in the central end of the distal segment of the divided nerve only a few days after they appear in the wound region, at first in small numbers and scattered here and there and then in progressively larger numbers as time advances. After the down-growing neuraxes have reached and penetrated the central end of the distal stump, the course of the majority of them becomes again quite regular and parallel to the long axis of

the nerve. Under favorable conditions new neuraxes may penetrate the central end of the distal stump before its nerves have reached the end stages of nerve degeneration, evidenced by the presence of nucleated syncytial bands, developed from the hypertrophied and proliferated sheath cells. In their downgrowth into the central end of the distal stump many of the downgrowing central neuraxes penetrate the neurolemma sheaths of the degenerating peripheral fibers, others are found in endoneural spaces between the nerve fibers, others pass along the inner or outer surface of the perineural sheath, others again are found in the epineurium. It is not unusual to observe several new neuraxes within one neurolemmal sheath of a degenerating nerve fiber of the distal stump and, in longitudinal sections of this region, neuraxes with end-

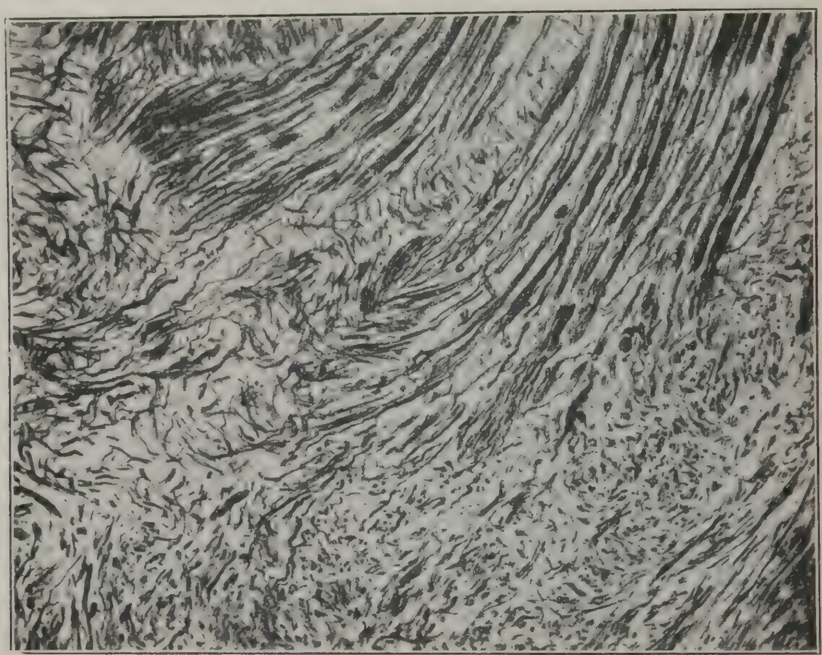

FIG. 215.—From a longitudinal section of the proximal zone of a neuroma on the sciatic of a dog, 31 days after section; pyridine-silver preparation. The figure presents the central down-growing neuraxes, in approximately parallel arrangement, so long as the down-growing neuraxes are in the main within the old neurolemma sheaths and the dispersed and irregular arrangement of the neuraxes as found in the scar tissue of the more distal zone of the neuroma

discs are often noted indicating the distal termination of a new neuraxis within the limits of the section. In cross or in longitudinal serial sections it can be readily determined that neurotization of the peripheral degenerated portion of a nerve progresses gradually from the region of the wound and suture toward the periphery and this at a rate which is estimated at from 1 mm. to 2 mm. in 24 hours. The progressive neurotization is not only in the distance of the penetration of the downgrowing central neuraxes but also in the increase in the number of neuraxes which reach the distal stump; this number gradually decreasing toward the periphery.

Attention has been called to the very great increase in the number of the neuraxes, formed by division and budding in the distal end of the central stump.

Only a variable percentage of these reach the distal stump through the wound region, proportionately more, the more favorable and shorter the path. The down-growing central neuraxes are diverted from their course toward the periphery in the organizing scar tissue in various ways. Certain of them are deflected centralward, ending in the endoneural tissue of the central stump. Others grow toward the edges of the wound and are lost in the surrounding connective tissue, while others pass to the fibrous layers of the peripheral stump outside of the funiculi. In experimental work, it has been observed, that the more successful the suture the earlier do downgrowing neuraxes reach the distal stump and the greater the number of downgrowing neuraxes which penetrate it. In case a primary suture is not made and the severed nerve ends are not in close

FIG. 216.—From a longitudinal section of a neuroma on the sciatic of a dog, 31 days after nerve section; pyridine-silver preparation. The figure makes evident the great increase in the number of down-growing neuraxes as found in the central zone of the neuroma, or proximal to the wound after severance and suture

approximation, even though there be not extensive separation, the down-growing central neuraxes become dispersed and deflected in their course in the organizing scar tissue forming the central end of a cut nerve resulting in the formation of an amputation neuroma, even in cases in which the central down-growing neuraxes ultimately reach the distal stump and bring about its partial neurotization. The down-growing neuraxes of the central stump, whether the branches of myelinated or of nonmyelinated fibers, in the wound region and in the distal stump are all at first nonmyelinated fibers. Whether these down-growing neuraxes are preceded or accompanied by sheath cells derived from the central fibers has not been determined conclusively. The modern silver methods which give such clear differentiation of neuraxes and terminal end-discs do not

differentiate equally clearly between cells derived from the ectodermal sheath cells and the cells derived from the mesodermal fibroblasts and both types of cells appear to form syncytial structures in the earlier stages of nerve repair. It is difficult to conceive of the relatively large end-discs of growing neuraxes, thought to have ameboid properties, as coursing within the nucleated protoplasmic bands. The same may be thought of the complex spiral structures or the numerous neuraxis buds growing from a single central neuraxis. Experimental embryologic evidence is at hand to show that neuraxes may grow without the presence of sheath cells; resulting in the formation of naked neu-

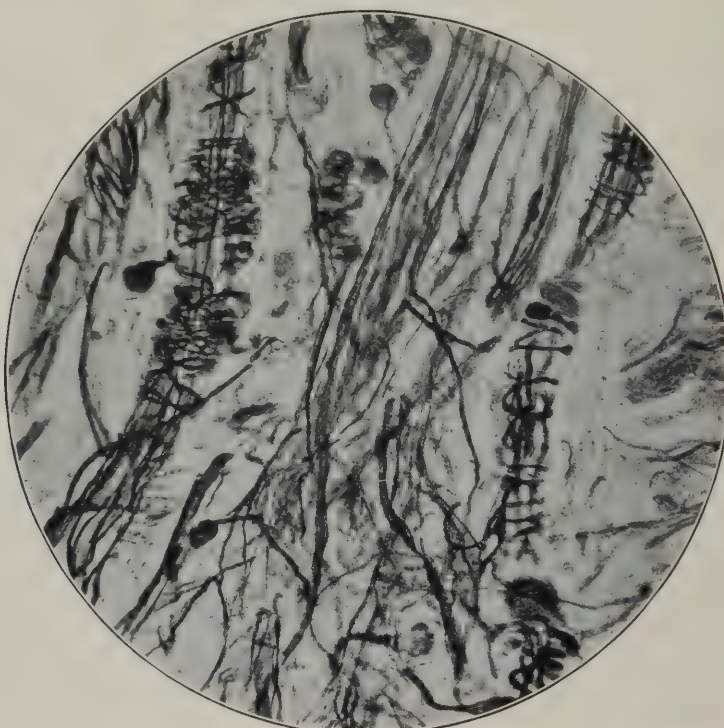

FIG. 217.—From a longitudinal section of a neuroma, removed three weeks after section of the sciatic of a dog; pyridine-silver preparation. Note the branching of neuraxes; the crisscrossing of neuraxes; prominent spiral formations and a number of typical though relatively large end-discs or incremental cones denoting the distal ends of down-growing neuraxes

raxes. What appear to be naked neuraxes are now and then followed for quite a long distance in the connective tissue or between the muscle fibers and this some distance from the wound. The statement has been made that the nucleated syncytial protoplasmic bands of the distal stump exert a chemotactic influence on the downgrowing neuraxes, drawing them toward the neurolemma sheath of the peripheral stump and influencing their downgrowth toward the periphery. This has not been experimentally demonstrated. There are often found several down-growing neuraxes in one neurolemma sheath of the distal stump, but they are also found between the nerve fibers of the funiculi and in the connective tissue outside of the perineural sheaths. The relation of the

down-growing neuraxes found within the old neurolemmal sheath to the nucleated syncytial bands also found within the sheaths has been interpreted differently by observers. They have been regarded either as playing a passive rôle or as forming conduits for the down-growing neuraxes. Ranson [39] thinks that all the new axons lie in protoplasmic bands and Boeke,[40] as a result of a study in which he made use of various technical methods, reached the conclusion that neurofibril strands are always intraprotoplasmic. Kirk and Lewis[47] believe that they have shown that the nucleated, syncytial, protoplasmic bands constitute conduits in the substance of which the nonmedullated nerve fibers regenerating from the proximal stump rapidly grow down, the bands forming first, the fibers following along them though they state that they do not wish to imply "that the axis cylinders always and necessarily track along the protoplasmic bands." The prevailing opinion at the present time regarding the down-growing neuraxes found in the peripheral neurolemma sheaths is that they have an intraprotoplasmic position. So far as has been determined there is at hand no evidence to warrant the conclusion that down-growing neuraxes show any selectivity on reaching the peripheral stump. Thus branches from the central motor neurons may and do, no doubt, enter the sheath of degenerating afferent or sensory nerve fibers and vice versa; and that nonmedullated central fibers may enter the sheaths of medullated peripheral fibers and vice versa. It has long been known that central motor fibers may grow into distal sensory fibers, and vice versa. This has recently been confirmed by Boeke.[41] Functional regeneration has not been attained although neuraxes are seen in the peripheral segments and a beginning in the formation of nerve terminations has been noted. It is assumed that chance brings as many down-growing central neuraxes of motor neuron origin to degenerated peripheral motor nerve fibers as of central fibers of other functional types and so for other types of nerve fibers. It has seemed to the writer that a simple mechanical explanation is perhaps the correct one. It may accordingly be assumed that developing neuraxes of the central stump, which reach degenerating homologous nerve fibers of the peripheral stump, develop the functional activity after the formation of the requisite nerve terminations; while down-growing central neuraxes which reach degenerating heterogeneous nerve fibers of the peripheral stump ultimately degenerate. The enormous increase in the number of central nerve fibers, through division and formation of side branches, permits many nerve fiber branches to go astray and ultimately to undergo degeneration by reason of want of functional activity and still leave a sufficient number to admit of structural and functional regeneration of a nerve going to a given part. The conclusion is, as a result of many experimental observations on nerve repair, that there is obtained at best only partial regeneration of the distal segment of a peripheral divided or injured nerve.

Huber,[48] Tello,[46] and Boeke [40] have studied the regeneration of the motor and sensory nerve ending in striated muscle tissue after experimental degeneration of nerves, with the aid of the intra vitam methylene blue method and certain silver precipitation neuraxis stains. Experimental observations show that a muscle responds to electrical stimulation of its nerve which had previously been degenerated, so soon as newly formed motor nerve endings can be demonstrated in said muscle by suitable staining methods. Down-growing neuraxes,

now and then terminating in end-discs can often be demonstrated in the interfascicular muscular branches when stimulation of the motor branches fails to incite muscular contraction. Developing motor endings in regeneration have been demonstrated as forming as the result of the branching of end discs, or as branches of collaterals led to the muscle fibers within the old neurolemma sheaths or along syncytial strands of sheath cells and perhaps along cells of connective tissue origin. There may be formed more than one nerve termination on a single fiber. Motor endings regenerate before sensory endings; possibly explaining a voluntary control of a muscle before there is synergic action of said muscle. Coarser or finer nerve fibers are often found within the capsule of neuromuscular and neurotendinous nerve endings before the endings show full development. Complete regeneration of the complex endings has been observed.

THE MYELIN SHEATH AND NEUROLEMMA SHEATH OF REGENERATING NERVE FIBERS

The silver precipitation methods used as differential staining for neuraxes, and used by nearly all observers in the more recent studies of nerve degeneration and regeneration are not suitable methods for the study of the histogenesis of the myelin or neurolemma sheath, so that these more recent observations have on the whole not contributed materially to the solution of this question. As has been stated, all down-growing neuraxes derived from the central stump, are at first nonmyelinated. It seems quite clear that such of these fibers as are destined to become myelinated acquire their myelin sheath beginning with the proximal end, and proceeding from here distalward. New myelinated nerve fibers can be recognized first in the distal end of the proximal segment of a divided nerve toward the end of the first month after injury in the form of very delicate and apparently continuous sheaths demonstrable in chromatized tissue treated by differential myelin staining methods. The structural appearances presented suggest the differentiation of the myelin sheath as a peripheral layer of the neuraxis, though this can not be stated without reservations. Myelin sheath formation proceeds distalward and does not involve all of the nerve fibers at the same time. This process of myelinization begins in the proximal stump before functional connection of the nerve fibers with formation of nerve terminations has been effected.

The neurolemma sheaths of regenerating nerve fibers appear to be new formations, developed from the sheath cells, which migrate with budding neuraxes or are found in situ by the down-growing neuraxes and derived through sheath cell proliferation during the process of degeneration of the nerve. The detail of the development and formation of the neurolemma sheath of regenerating nerve fibers has not been definitely determined.

EXPERIMENTAL OBSERVATIONS

The experimental observations to be recorded and discussed in the following pages deal in a large measure with the question of bridging nerve defects in peripheral nerves, due to loss of substance. These defects were bridged by nerve transplants or otherwise. No experimental observations on simple, primary, or secondary end-to-end suture of a severed nerve were made. The

end-to-end suture of a divided peripheral nerve, either as a primary or a secondary operation, is a recognized procedure in surgery, even though there may not be full agreement as to technical details of the operation. The differences of opinion as to the technique of end-to-end suture of a divided nerve were not such as seemed to warrant extended experimentation at a time when other questions seemed to be more pressing. The same can not be said for operative procedure suggested and used for the repair of a divided nerve after loss of substance. The various methods which have been suggested to bridge the gap between the severed ends of a peripheral nerve in case there is loss of tissue to the extent that the severed ends can not be brought together without undue tension were reviewed by Huber [49] and critically considered in the light of experimental observations. Such operative procedures include the formation of a nerve flap from either the central or distal stump or both; operations of nerve implantations; operations of nerve crossing, either complete or incomplete; suture à distance; tubular sutures and nerve grafting or nerve transplantation. The value of the nerve flap in the repair of peripheral nerves was tested experimentally by Huber [30] and discredited and shown to be of no value by Stookey [50] as a result of a critical review of all the reported cases. Nerve implantation consists of the insertion of the severed end of one nerve, either the central or distal end or both, into the interfunicular tissue of an adjacent nerve. By multiple or serial implantation is meant where one or several parallel nerves are injured, with loss of substance and are then serially implanted (Hofmeister).[51] Neither of these operations can be approved since on implantation of the central stump of a divided nerve into the interfunicular connective tissue of a sound nerve there is not furnished a suitable path for the downgrowth of central neuraxes; the less so in serial implantation. By nerve crossing is here meant the suture of the central end, complete crossing, or a flap from a normal nerve, incomplete nerve crossing, to the distal end of another nerve. It has been shown experimentally that complete and incomplete nerve crossing are feasible and logical procedures, whether made as a primary or a secondary operation. In selecting this as the operation of choice it needs to be decided whether other operative procedure may not offer more favorable end results when considering both of the nerves involved. It should be understood that in the operation of complete crossing, in forming the central flap, the sound nerve is injured to the extent of the flap and paralysis will ensue in the field of the cut fibers, not relieved or only partially relieved by the accidental downgrowth of central neuraxes from the parent nerve. In suture à distance a bundle of catgut strands has been used to bridge a defect in a divided nerve with loss of substance by Huber [30], with some success as concerns neurotization of the distal stump. However, other methods offer greater opportunity for bridging nerve defects. Muscle and tendon fibers, woolen, silk, and other fibers have been used for suture à distance with unfavorable results and need receive no further consideration here. The operation of uniting the separated ends of a divided nerve by means of a tube through the lumen of which the central neuraxes were thought to be directed to the distal stump—tubular nerve suture—is an old operation and has received more than incidental attention by surgeons even in relatively recent years. A variety of materials have been

used, not all of which have been tested experimentally. Of materials used at operation or in experiments, mention is here made of decalcified bone tube, iodoform gauze, epidermis of man, magnesium tubes, hardened-gelatine tubes, rubber tubes and sheet rubber wrapped to form a tube, galalith tubes, hardened arteries and fresh arteries and veins, fascia lata and other connective tissue membranes, peritoneum, Cargile membrane, celloidin tubes, arteries filled with agar, as suggested by Edinger and extensively used for a brief period in the German army. Certain of these materials for tubular nerve suture were given consideration in our experimental work and will be discussed in connection with the experimental observations. Other materials used are really more of academic interest than of practical use and their consideration need not occupy space here. Nerve grafts or nerve transplants were given extensive consideration in our experimental work, new methods were devised which, judging from experimental results, should receive favorable consideration at the hands of surgeons in dealing with the repair of injured nerves after loss of substance. We have followed surgical usage and have designated a nerve segment from another nerve of the same individual as an auto-nerve-transplant; a nerve segment taken from another individual but of the same species as a homo-nerve transplant; a nerve segment taken from another individual but of a different species, a hetero-nerve transplant.

The literature dealing with both the clinical and the experimental phases of the question of repair of peripheral nerves after loss of substance is an extensive one, too extensive to be reviewed here. Certain of the contributions will be considered in connection with the discussion of the experimental observations. Many citations are given by Huber [49] and by Stookey [9], who give critical reviews of clinical and experimental observations.

The experimental observations to be discussed here will be considered under the following heads:[a]

Series No. 1. Injection of absolute alcohol into a normal nerve, without subsequent cutting of the nerve; 12 experiments.

Series No. 2. Injection of full-strength acetone into a normal nerve, without subsequent cutting of the nerve; 3 experiments.

Series No. 3. Injection of absolute alcohol into the central end of a divided nerve to obviate the formation of an amputation neuroma; 37 experiments.

Series No. 4. Amputation neuroma formation in aseptic wounds; 12 experiments.

Series No. 5. Auto-nerve transplants, including cable auto-nerve transplants; 17 experiments.

Series No. 6. Homo-nerve transplants; 6 experiments.

Series No. 7. Hetero-nerve transplants, mainly guinea pig's nerves to rabbits, also nerves of dogs to rabbits; 39 experiments.

Series No. 8. Degenerated auto-nerve transplants; 3 experiments.

Series No. 9. Degenerated homo-nerve transplants; 5 experiments.

Series No. 10. Degenerated hetero-nerve transplants; 16 experiments.

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[a] Brief preliminary reports have been given of these experimental observations before the Chicago Neurological and Pathological Societies (Huber),[52] and before the Chicago Surgical and Neurological Societies (Huber),[53] Reports of progress were given by Huber[53] on special detail before the Neurosurgical School in New York City.

Series No. 11. Homo-nerve transplants which had been stored in sterile vaseline at 3° C.; 8 experiments.

Series No. 12. Homo-nerve transplants which had been stored in sterile liquid petrolatum at 3° C; 40 experiments.

Series No. 13. Homo-nerve transplants which had been stored in 50 per cent alcohol at room temperature; 19 experiments.

Series No. 14. Hetero-nerve transplants, dog's nerve to rabbit; stored in sterile liquid petrolatum at 3° C.; 6 experiments.

Series No. 15. Hetero-nerve transplant, dog's nerve to rabbit, stored in 50 per cent alcohol; 3 experiments.

Series No. 16. Auto-nerve transplants, wrapped in Cargile membrane; 14 experiments.

Series No. 17. Auto-nerve transplants, wrapped in auto-fascial sheaths of fascia lata; 14 experiments.

Series No. 18. Auto-nerve transplants, wrapped in formalized arterial sheaths; 6 experiments.

Series No. 19. Auto-nerve transplants, wrapped in auto-fat sheaths; 2 experiments.

Series No. 20. Tubular sutures with use of formalized arteries; 13 experiments.

Series No. 21. Tension sutures; resected nerve sutured under extreme tension, with or without wrapping in Cargile membrane or formalized arterial sheaths; 13 experiments.

All of the operative work was carried out under strict asepsis and by surgeons on special detail for experimental nerve surgery. This work was very carefully done, especially as pertains to the technique of the operative work on the nerves. Special care was exercised in placing sutures so as to obtain accurate coaptation of the severed nerve ends, to stay all hemorrhage, and to obviate clot formation between the severed nerve ends. In practically all of the experimental operations healing of the wound was attained by primary intention; when otherwise, notation is made in the respective protocol. In the several series of experiments undertaken the respective animals were kept under observation for periods which varied in the several experiments from one day to about a year. Very few animals were lost as a result of operation. There was evidently great difference in resistance to disease. Now and again epidemics would interfere with the schedule of experiments, though not always with complete loss of the experiment. At fixed times the animals operated upon were killed and the operated nerves exposed and gross observations recorded. Functional tests were made in nearly all cases in which return of function was crucial to the experiment. After exposure of the nerve and the making of the necessary functional tests the operated nerve was removed for histologic study. In cases in which the operated animals died during the night, especially if this occurred in an experiment in which some time had elapsed since the initial operation, equally careful exposure of the operated nerve was made and a histologic study undertaken. In nearly all of the experiments a segment of the nerve central to the wound region, the wound region, and the portion of the nerve distal to the wound were removed for

histologic study, and sectioned serially in alternate longitudinal and crosscut series. Considering the primary purpose of these series of studies, namely, the opportunity of applying in practical surgery the conclusions reached in the work of repair of peripheral nerves, our attention was especially directed toward the behavior of the central neuraxes in the process of neurotization of the peripheral segment, the sine qua non of peripheral nerve repair. It was necessary to determine on a reasonably reliable differential neuraxis stain, one that could be used in staining en masse and permit of paraffin embedding to facilitate, so far as possible, the making of serial sections, so essential to the adequate study of the problem in question. After brief trial of several methods the pyridine-silver method of neuraxis staining (Ranson) was selected and the great majority of the histologic sections made were stained after this method. The essential steps of the pyridine-silver method of neuraxis staining are as follows: 1. Fixation of tissue in ammoniated absolute alcohol for 2 to 3 days. The ammoniated alcohol is prepared by adding 1 c. c. of strong ammonia water to 100 c. c. of absolute alcohol. A relatively large quantity of the fixative is essential. 2. Wash for about 2 minutes in distilled water. 3. Place for 24 hours in pyridine. 4. Wash in distilled water for 24 hours, changing the water frequently. 5. Place in 2 per cent aqueous solution of nitrate of silver, in which the tissue remains for 3 to 5 days, in the dark and at a temperature of 32° C. to 35° C. 6. Rinse in distilled water and place for 1 to 2 days in a pyrogallic acid-formalin solution prepared by dissolving 4 gms. of pyrogallic acid in 100 c. c. of 5 per cent formalin. Keep in the dark and at a temperature of 32° C. to 35° C. 7. After washing in distilled water for several minutes dehydrate in graded alcohol, beginning with 80 per cent alcohol. The dehydration needs to be thoroughly done; several changes of absolute alcohol are required. 8. Clear in xylol and embed in paraffin. A necessary stay in the warm oven even for 48 hours, to insure thorough penetration of the paraffin, does not deleteriously affect the stain.

The great bulk of the sections stained by the pyridine-silver method were cut serially by Huber's "water on the knife" method with the knife in the oblique position and on the sliding microtome. The sections as cut were arranged serially on the slide and fixed to the slide by the water-albumin fixation method and warmed to attain flattening of the sections. After removal of the paraffine thorough dehydration and clearing in xylol, the sections were mounted under cover glass in damar. Attempts at contrast staining were made but not generally used. In successfully stained preparations after use of the pyridine-silver method the nonmyelinated neuraxes stain a nearly black or brown-black or dark brown color, which usually contrasts quite distinctly with the yellow-brown color of the connective tissue. The neuraxes of myelinated fibers of the central stump, especially of the larger nerve fibers, are of a light brown or yellowish-brown color. The Perroncito spirals and the incremental cones or end-discs are very clearly differentiated. The myelin sheaths are not differentially stained. The nuclei of the neurolemma sheaths and of the fibrous connective tissue cells and fibroblasts of growing fibrous tissue, may or may not be differentiated, usually not clearly nor certainly enough to determine definitely questions concerning their participation

in the downgrowth of central neuraxes. The Bielschowsky method and this method as modified by Boeke in his studies of degeneration and regeneration of nerves, as also Cajal's methods, were used; but they did not give as reliable and constant results as the pyridine-silver method. The pyridine-silver method does not give as satisfactory results in cases where the tissues are removed several hours after death, though in certain of the experiments in which the animal died during the night, very successful staining of the neuraxes was attained. It should be understood that with all silver precipitation methods of neuraxis staining, as with intra vitam methylene blue method, positive results can be received with much greater assurance than negative results. The fact that no neuraxes are found stained in such preparations is not proof positive of their non existence. Certain of the operated nerves were fixed in formalin and after chromatization stained in differential myelin stains, in iron-lac-hematoxylin or double stained in safranine and licht grün. In other cases the nerve was fixed in chrom-acetic-osmic acid mixture and stained in safranin and licht grün. The experiments in which these latter histologic methods were used in place of the pyridine-silver method are relatively few and mostly in experiments of short duration.

INJECTION INTO LIVING UNCUT NERVE

SERIES NO. 1

INJECTION OF ABSOLUTE ALCOHOL INTO A LIVING NERVE WITHOUT CUTTING THE NERVE

Schlösser [54, 55] introduced the use of alcohol injection into a nerve trunk or the tissue surrounding the nerve trunk for the relief of neuralgia or other peripheral nerve irritations. Brissaud, Sicard, and Tanon [56] record the use of alcohol injection for facial spasms. Since then the method has been extensively used in the operative relief for neuralgic conditions. Experimental observations on alcohol injection into a living nerve trunk are first recorded by Finkelnburg [57] who, taking part in a general discussion on the treatment of neuralgia, reports briefly on experimental observations in which 0.6 c. c. to 1.5 c. c. of 60 per cent to 80 per cent alcohol was injected into the sciatic of dogs after exposure of the nerve or into the tissues surrounding the nerve. A complete paralysis was produced on injecting the nerve, lasting for months, with complete degeneration of the nerve in the wound region and the peripheral segment of the nerve. A much more extended and careful study of the question was undertaken by May.[58] He injected the infraorbital as a pure sensory nerve, the sciatic and anterior crural as mixed nerves, and also the Gasserian ganglion. General histologic methods, as also Cajal's and Bielschowsky's silver impregnation methods for neuraxis staining, were used. The protocols of the experiments made are given, as also figures illustrative of the changes resulting in the nerve on injection of alcohol. The following are certain of the conclusions reached by May: [58]

1. Alcohol injected into the trunk of a peripheral nerve produces more or less complete local necrosis of the nerve at the point of injection.

2. The change is not an ascending one; the nerve above the point of injection remains normal; the cells of origin of the fibers may show some degree of chromatolysis, but do not exhibit signs of permanent injury.

3. The conditions produced by such injection are more favorable to regeneration than those resulting from simple section without suture. The anatomical continuity of the nerve trunk favors rapid regeneration, though this is to some extent retarded by the fibrosis which occurs to a greater or less extent in every case of alcohol injection.

Harris [59, 60] and Patrick [61] have reported extensive clinical observations, dealing mainly with the injection of the trigeminal ganglion for the relief of trifacial neuralgia, an operation experimentally studied by May.[58] The injection of a nerve trunk with alcohol in causalgia was first recommended by Sicard[62] and has since received consideration by a number of other observers, who have used the method with success.

The experimental observations in this series were undertaken with a primary view of gaining experimental data for comparison and correlation with the experiments reported upon under Series No. 3, dealing with the amputation neuroma. The histologic findings in the several experiments are of interest per se, especially as concerns the more immediate effects of the alcohol on the living nerve fibers. Our observations were made on the sciatic nerve of the rabbit. This nerve, in the rabbit, can be exposed from the popliteal space to the sciatic notch with very little bleeding. The exposed nerve was then freed from its bed at about the middle of its course and raised slightly on a blunt hook and injected through a fine hypodermic needle inserted if possible beneath the perineural sheath of the large funiculus and into the epineural sheath surrounding the smaller funiculi and in a direction nearly parallel to the long axis of the nerve. The injection of the alcohol was made slowly and with the nerve exposed, so as to enable the observer to follow the immediate result of the injection. The nerve for the length of 1.5 cm. to 2 cm. presents, after successful injection, a "milky white" appearance. The few drops of alcohol which might escape into the wound were taken up with cotton. The wound was then closed with deep catgut or silk stitches and the skin wound with interrupted silk stitches.

PROTOCOLS

Experiment No. 1.—Rabbit No. 24a. Large; full grown; 1 hour. March 12, 1918, 4 p. m., right sciatic exposed and injected while in place, with absolute alcohol. Nerve not cut. Wound closed. March 12, 5 p. m., wound opened, one hour after alcohol injection. A slight hemorrhage is found at the point of injection. The part of the nerve affected by the alcohol, a little over 1 cm. in length, presents a dull white appearance. The sciatic removed and fixed in neutral formalin. Bielschowsky's differential staining method used.

Microscopic findings.—In series of longitudinal sections, including the field of alcohol injection and the nerve trunk adjacent, central and distal thereto, it may be observed that in the nerve fibers found in the field of alcohol injection the neuraxes are not interrupted and present the staining reaction of normal neuraxes. The myelin of many of the fibers presents a distinctly granular appearance; the granules appear to have been derived from the neurokeratin net. In other fibers the "Golgi funnels" are clearly differentiated. The neurolemma sheaths in the injected field are well maintained; of regular contour and found deeply stained. Not as yet distinct structural changes noted as the result of alcohol injection.

Experiment No. 2.—Rabbit No. 40a; full grown; 3 hours. March 23, 1918, 11 a. m., left sciatic exposed and injected while in place with absolute alcohol. Nerve not cut. Wound closed. March 23, 2 p. m., three hours after alcohol injection. Wound opened and left

sciatic exposed. The area of alcohol injection recognized by the dull white appearance presented by the nerve trunk in this region. This area extends along the length of the nerve trunk for a distance a little over 1 cm. Calf muscles do not contract when nerve is cut central to field of alcohol injection. The nerve removed and fixed in neutral formalin. Bielschowsky's silver stain used.

Microscopic findings.—Of the several series of longitudinal sections, in those including the injected area, it may be observed that the neuraxes of the nerve fibers found in the alcohol injected area are as yet unfragmented and show normal differential staining. In one small area a few segmented neuraxes noted. The myelin sheaths present a distinctly granular appearance; neurolemma sheaths have normal appearance. The nerve fibers of this area present structurally no distinct departure from that presented by the normal fibers.

Experiment No. 3.—Rabbit No. 61a; large; full grown; abscess on neck; 6 hours. March 23, 1918, 11.20 a. m., the right sciatic exposed and injected while in place with absolute alcohol. Nerve not cut. Wound closed. March 23, 5.20 p. m., wound opened and sciatic exposed. Area of alcohol injection easily recognized by its dull white color. Muscles do not contract when nerve is cut central to field of injection. Nerve fixed in neutral formalin. Bielschowsky's silver staining method used.

Microscopic findings.—In several series of longitudinal sections including the area of alcohol injection, in the immediate alcoholized field and especially in the larger internal popliteal bundle, many of the nerve fibers are found to contain fragmented neuraxes. These fragments of neuraxes are of longer or shorter length; certain of the fragments present a wavy course; others are coiled. Certain other neuraxes present a granular disintegration. In the external popliteal funiculus, fragmentation of neuraxes not so distinct. The myelin of the nerve fibers presents a granular appearance; the neurolemma sheaths are found well maintained.

Experiment No. 4.—Rabbit No. 6a; large; full grown; 1 day. February 21, 1918, right sciatic exposed and injected while in place with absolute alcohol. Nerve not cut. Wound closed. February 22, killed, 24 hours after injection; wound opened and nerve exposed. Area of alcohol injection recognized by dull white color of nerve in the region of alcohol injections. Muscles do not contract on cutting central sciatic. Nerve removed and fixed in neutral formalin. Bielschowsky's silver staining method used.

Microscopic findings.—Several series of longitudinal sections made. In the series including the field of alcohol injection numerous fragmented neuraxes are found. These neuraxes fragments stain differentially in the silver stain; they vary in length; many are distinctly coiled, like a spiral spring; others present a wavy course; others show alternate enlargements and constrictions. Many of the nerve fibers more peripherally placed in the sections do not show this neuraxis fragmentation. Presumably such fibers were not affected by the alcohol. In the affected nerve fibers the myelin presents a granular appearance; the neurolemma sheaths do not show a distinct structural change.

Experiment No. 5.—Rabbit No. 6; large; full grown; 2 days. February 20, 1918, left sciatic exposed and injected in place with absolute alcohol. Nerve not cut. Wound closed. February 22, killed, two days after alcohol injection. On exposing the nerve the area of alcohol injection is recognized by its dull white color. The nerve removed and fixed in neutral formalin. Bielschowsky's silver staining method used.

Microscopic findings.—Several series of longitudinal sections made. In such of the sections as include the field of alcohol injection, the majority of the neuraxes are found fragmented into longer and shorter segments, which take the differential silver stain. Many of these neuraxis segments appear to be breaking up into granules, which granules are differentially stained. A certain number of nerve fibers having unfragmented neuraxes are found here and there in the sections. Nerve fibers with fragmented and unfragmented neuraxes are often found in close proximity. The myelin of the nerve fibers distinctly granular; the neurolemma sheaths found of normal contour and appear structurally well preserved. The sheath cells not clearly differentiated.

Experiment No. 6.—Rabbit No. 7a; full grown; 3 days. February 22, 1918, right sciatic exposed and while in place injected with absolute alcohol. Nerve not cut. Wound closed.

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February 25, killed. On exposing the nerve the field of alcohol injection recognized by the dull white color assumed by the nerve in this region. Nerve removed and fixed in neutral formalin. Bielschowsky's silver staining method used.

Microscopic findings.—Several series of longitudinal sections made. In such as include the field of alcohol injection, it is observed that nearly all of the neuraxes of the nerve fibers show a fragmentation. The majority of these neuraxes segments are of relatively short length, many of which appear to be breaking down into granules. In certain of the nerve fibers neuraxes segments are no longer evident. Here and there in the field, nerve fibers with unbroken neuraxes are to be seen. The myelin of the nerve fibers presents a granular appearance; neurolemma sheaths well maintained.

Experiment No. 7.—Rabbit No. 7; full grown; 4 days. February 21, 1918, left sciatic exposed and while in place injected with absolute alcohol. Nerve not cut. Wound closed. February 25, killed. Wound nearly healed. On exposing the sciatic, area of injection with absolute alcohol no longer dull white color, but appears slightly congested; has not the glistening appearance of normal nerve trunk. Sciatic removed and fixed in neutral formalin. Bielschowsky's silver staining method used.

Microscopic findings.—Several series of longitudinal sections made. In such as include the area of alcohol injection, the neuraxes of nearly all of the nerve fibers found broken in segments of very variable length; relatively few unfragmented neuraxes observed. In many of the neurolemma sheaths, no longer any fragments of neuraxes found; in others again the neuraxes segments are quite long and of wavy or spiral course. The myelin of the nerve fibers granular; neurolemma sheaths of the great majority of the fibers seem well preserved.

Experiment No. 8.—Rabbit No. 61; large; full grown; abscess on back; 11 days. March 12, 1918, left sciatic exposed and while in place injected with absolute alcohol. Nerve not cut. Wound closed. March 23, killed, wound well healed. The area of alcohol injection not clearly defined. For a short segment the nerve seems congested. Sciatic removed and fixed in neutral formalin. Bielschowsky's silver staining method used.

Microscopic findings.—Three series of longitudinal sections made, of a little over 3 cm. of the nerve trunk including area of alcohol injection. In such sections as include the area of alcohol injection, the neurolemma sheaths of the nerve fibers clearly made out; within the great majority of these a granular detritus with only here and there a fragment of neuraxis remaining. In other neurolemma sheaths deeply stained globular masses; the histogenesis of which is not clearly made out. Evidence of in-wandering of leucocytes is noted; though the stain used does not clearly define these. In longitudinal sections of the nerve distal to the field of alcohol injection, the microscopic field is quite different. In such segments longer and shorter segments of neuraxes are found, differentially stained. A few fibers in which unbroken neuraxes are present are seen. The distal nerve segment sectioned presents the appearance of degenerating peripheral nerve fibers.

Experiment No. 9.—Rabbit No. 26a; full grown; 62 days. March 19, 1918. Right sciatic exposed and while in place injected with absolute alcohol. Nerve not cut. Wound closed. May 23, killed. Severe neurotrophic changes right hind foot. On exposing the right sciatic the region of alcohol injection is detected by reason of a slight discoloration of nerve; in this region it does not present the white glistening appearance of a normal nerve trunk. No twitching nor contraction of the calf muscles is observed on cutting the nerve either central or distal to field of alcohol injection. Nerve removed and fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation attained.

Microscopic findings.—Several series of longitudinal sections made. In such sections as include the nerve just central to the place of injection, numerous smaller and larger bundles of neuraxes, having in the main a longitudinal course, but here and there exchanging fibers are found, separated by long, spindle-shaped areas containing granular detritus and large vesicular cells, mutually compressed. In cross sections of the nerve in approximately the middle of the field of alcohol injection, it may be observed that the fibrous sheaths of the nerve are thickened, and that the funicular structure of the nerve is lost. Numerous neuraxes arranged in smaller and larger groups are observed in cross sections. Areas of vesicular cells and granular detritus are here and there evident; some few neuraxes are found in such areas. In cross section of the nerve trunk, approximately 2 cm. distal to the place of alcohol

injection, the funicular structure of the nerve is again observed, with new down-growing neuraxes observed in all of the funiculi.

Experiment No. 10.—Rabbit No. 65; full grown; 66 days. March 21, 1918, the right sciatic exposed and while in place injected with absolute alcohol. Nerve not cut. Wound closed. May 25, killed; much emaciated; for three weeks posterior extremities partially paralyzed. Cause not ascertained. On exposing the right sciatic, in what appears as the region of alcohol injection the nerve trunk shows distinct spindle-shaped enlargement; nerve is here somewhat adherent to the surrounding connective tissue. No contraction of calf muscles on cutting nerve central or distal to place of alcohol injection was observed. Nerve removed and fixed in ammoniated alcohol for pyridine-silver staining. No wholly successful silver differentiation of neuraxes attained.

Microscopic findings.—Three series of longitudinal sections made, including the field of alcohol injection. In these series it can be observed that numerous neuraxes growing from the central portion of the nerve have reached the portion distal to the field of alcohol injection. In longitudinal sections including the region of the spindle-shaped enlargement bundles of neuraxes are found to cross and crisscross in all directions. These microscopic fields give the impression that many of the nerve fibers were torn at the time of alcohol injection, the appearance being that of neuraxes passing through a fibrinous wound region. Distal to this spindle-shaped enlargement, they have a more regular longitudinal course much as seen in regenerating peripheral stump. The differential staining in this series is not wholly satisfactory; neuraxes in sufficient numbers were found differentially stained so that their course could be determined at different levels.

Experiment No. 11.—Rabbit No. 46a; full grown; 71 days. March 20, 1918, right sciatic exposed and injected while in place with absolute alcohol. Nerve not cut. Wound closed. May 31, rabbit found dead in the morning; severe neurotrophic changes in the right hind foot. On exposing the right sciatic in the region of alcohol injection, the nerve trunk presents a slightly smaller diameter and appears slightly congested; there is further a light yellow color. The distal segment presents the appearance of a degenerated nerve. Sciatic removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—Three series of longitudinal and one of cross sections made. In series of longitudinal sections including the field of alcohol injection, numerous larger and smaller bundles of neuraxes having in the main a longitudinal course are to be observed; between these bundles of neuraxes long spindle-shaped areas or columns composed of granular detritus and mutually compressed vesicular cells occur. In the series of cross sections made through the field of alcohol injections, the main funiculi (internal and external popliteal) are found demarked. Neuraxes arranged in smaller or larger groups and seen in cross section are found; these are separated by irregularly round or oval areas composed of granular detritus and vesicular cells. In the longitudinal sections made distal to the field of alcohol injection the nerve presents the appearance of a regenerating peripheral nerve.

Experiment No. 12.—Rabbit No. 64; full grown; 137 days. March 21, 1918, right sciatic exposed and while in place injected with absolute alcohol. Nerve not cut. Wound closed. August 5, killed. Rabbit in good condition; small neurotrophic ulcer on right heel. On exposing the sciatic, this in the middle of the thigh, the region of the alcohol injection presents for a length of about 1.5 cm. a somewhat smaller diameter than the nerve central and distal thereto, and presents the appearance of a normal nerve though the funicular structure can not be made out and is in this region moderately adherent to the underlying muscle. On cutting the sciatic central and then distal to the field of alcohol injection, after exposure of the calf muscles, these muscles were seen to contract and twitch. Sciatic removed and fixed in ammoniated alcohol. Fair silver differentiation attained.

Microscopic findings.—Series of longitudinal and cross sections were made at successive levels. Nerve fibers, certain of which are myelinated, can be traced from the central nerve through the field of alcohol injection to the distal nerve. In cross sections of the nerve through the field of alcohol injection, it can be seen that the funicular structure of the nerve is lost in this region. The neuraxes are found arranged in smaller and larger bundles, separated by strands of endoneural connective tissue, which is very materially increased in this region.

Very little remains of the old nerve fibers observed. The nerve distal to the field of alcohol injections contains numerous both myelinated and nonmyelinated nerve fibers. The muscle tissue was not studied in sections.

SUMMARY AND CONCLUSIONS

In Experiment No. 1, in which the nerve was removed for study one hour after the injection of absolute alcohol, the gross changes observed in the nerve in the field of injection were more evident than the microscopic changes. In the region of the spread of the alcohol, the nerve is coagulated, appears "milky white" or "dull white" and there is evidence of capillary hemorrhage. Unfortunately the record of this case does not state whether the nerve responded to mechanical stimulation on being cut central to the region of acohol injection. There is only very slight evidence of structural change in the region of alcohol injection as seen under the microscope when the nerve is removed soon after the injection; the neuraxes of the nerve fibers presenting, on the whole, a normal appearance and showing normal staining reaction on silver impregnation.

In Experiments No. 2, No. 3, and No. 4, in which the nerve was removed for study at a progressively longer period after the injection of alcohol, beginning with three hours after the operation, the nerve did not respond to mechanical stimulus on being sectioned central to the field of injection, while the nerve distal to this field presented normal structure and function. In the field immediately influenced by the injected alcohol, there is evident a fragmentation of neuraxes and myelin sheaths of nerve fibers not comparable to that observed in secondary degeneration, in that the change is not accompanied by proliferation of sheath cells and comes on soon after injury. Not all of the nerve fibers of an injected nerve trunk are equally affected. A certain number of nerve fibers, the number varying in the several experiments, appears not to be affected by the alcohol. The number of nerve fibers not affected, it would seem, is greater in case the alcohol is injected into the surrounding tissue rather than into the nerve trunk. Beginning with the third day after the alcohol injection, the neuraxes fragments, many of which may still stain differentially, begin to show evidence of further breaking down and, by the eleventh day after alcohol injection, the neurolemma sheaths (the sheaths of Henle?) are found filled with a granular detritus in which neuraxis fragments may or may not be found. The breaking down nerve fibers in the region of alcohol injection do not present the successive stages of secondary nerve degeneration, leading to the formation of nucleated, syncytial, protoplasmic bands, but present a microscopic picture which resembles more that of a nerve transplant removed some 10 to 15 days after transplantation. The segment of the nerve peripheral to the field of alcohol injection, on the other hand, presents the histologic changes characteristic of secondary nerve degeneration, as also the region immediately central to the field of alcohol injection.

In a nerve removed approximately two months after alcohol injection, Experiments No. 9 and No. 10, there is found abundant evidence of regeneration, although this has not extended far into the distal segment. In the region of alcohol injection, readily recognized in section, remains of the old nerve fibers are found in the form of granular detritus and also there are found large vesicular cells with relatively small nuclei, presumably with phagocytic function,

arranged in irregular columns or spindle-shaped areas; these may be found within or between old neurolemma sheaths and endoneural connective tissue septa. In this region there are found new neuraxes grouped in smaller and larger bundles, traceable to the central segment, having in the main a longitudinal course but here and there exchanging neuraxes. The new neuraxes did not appear in the distal regions of the peripheral segment. In only one experiment, No. 12, was the animal kept for a period long enough to admit a regeneration of the distal segment. In this experiment the nerve was removed somewhat over four months after the operation, at which time there was functional evidence of nerve regeneration. The region of alcohol injection is recognized by the absence of funicular structure, which structure is evident central and distal to the region. Bundles of nerve fibers, both myelinated and nonmyelinated, are found in the "wound" region, separated by relatively large areas of connective tissue. These bundles have in the main a longitudinal course but are serpentine as they wind through the connective tissue. The appearance of a wound region after severance and suture of a nerve trunk with not especially good approximation of ends is not unlike that of the region of alcohol injection followed by regeneration, except that this special area in an old alcohol injected nerve extends over a longer distance in the course of the nerve. Peripheral to the region of alcohol injection the process of regeneration is as after nerve section. The conditions resulting from injection of alcohol into a nerve trunk May [58] speaks of as a "chemical section" of the nerve and thinks that it is probable that regeneration would follow more quickly than after mechanical section. This, it would seem, depends entirely on the thoroughness and extent of the alcohol injection. If a number of point injections are made extending over several centimeters of nerve the resulting fibrosis would be quite extensive.

So far as can be determined there is no selective action as regards afferent and efferent nerves as a result of alcohol injection. In cases of causalgia in which 60 per cent alcohol was injected, it was thought by certain observers that motor functions might persist even though reaction of degeneration were present. It is difficult to explain such selective action, except on the possible ground that the larger myelinated motor nerve fibers are more resistant to the weaker solutions of alcohol than the smaller myelinated or nonmyelinated fibers of the exteroceptive pain and temperature functional systems. In cases of causalgia treated by the injection of alcohol into the respective nerve, ultimate regeneration of the injected nerve may be anticipated with reasonable assurance.

SERIES NO. 2

INJECTION OF FULL STRENGTH ACETONE INTO LIVING NERVE WITHOUT CUTTING THE NERVE

In this series of three experiments full strength acetone was injected into the sciatics of rabbits precisely as was described for Series No. 1, except that acetone solution was used instead of absolute alcohol.

PROTOCOLS

Experiment No. 13.—Rabbit No. 32a; full grown; 65 days. March 19, 1918, right sciatic exposed and injected with about 0.5 c. c. of full strength acetone. Nerve not cut.

Appearance of portion of nerve injected resembles closely that obtained when absolute alcohol is injected; dull white color. Wound closed. May 23, killed. Rabbit presents severe neurotrophic changes right hind foot. On exposing the right sciatic, increase of connective tissue about nerve in region of acetone injection; when nerve is dissected free, nerve trunk presents slight enlargement in this region. Calf muscles exposed; atrophic. Muscles did not contract on cutting nerve central and distal to field of acetone injection. Sciatic removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—Four series of longitudinal sections were cut taken at successive levels and including the field of acetone injection and the nerve just proximal and distal thereto. In the series of sections including the nerve about 1.5 cm. proximal to the point of acetone injection, practically normal nerve structure is observed, the stained neuraxes, both myelinated and nonmyelinated, having a longitudinal direction. Here and there "end discs," the distal ends of down-growing neuraxes, are encountered. In longitudinal sections of the immediate field of acetone injection, numerous neuraxes in the form of larger and smaller bundles, having in the main a longitudinal course, but here and there interchanging fibers, are encountered. These bundles of neuraxes are separated by areas and columns of vesicular cells with small nuclei as well as granular detritus. Areas of crisscrossing of neuraxes are here and there encountered. In more distally placed sections many neuraxes are found growing distalward on the inner surface of the perineural sheath; such neuraxes interlace and have a plexus form of arrangement. In sections placed distal to the field of injection, new nerve fibers are found in large numbers, having again a longitudinal course. The nerve trunk in this region presents the appearance of a regenerating peripheral nerve after severance of continuity.

Experiment No. 14.—Rabbit No. 35a; full grown; 78 days. March 19, 1918, right sciatic exposed and injected while in place with full strength acetone. Nerve not cut. Wound closed. June 5, rabbit found dead in the morning. On exposing the right sciatic this is found nonadherent to the surrounding connective tissue. In the middle of the thigh, the region of acetone injection, the sciatic presents a short segment having a light yellow color. The nerve of this region is not thickened nor adherent. Sciatic removed and fixed in ammoniated alcohol for pyridine-silver staining. Only in part successful silver differentiation attained.

Microscopic findings.—In the several series of longitudinal sections made, sufficiently good silver differentiation obtained to determine the fact that central down-growing neuraxes, in large numbers, pass through the field of acetone injection into the nerve trunk distal to this field. In the field of acetone injection are observed areas and columns of granular detritus and large vesicular cells, separating bundles of neuraxes. At the point of injection, distinct increase of endoneural and perineural connective tissue is noted.

Experiment No. 15.—Rabbit No. 53a; nearly full grown; 323 days. March 20, 1918, right sciatic exposed and injected while in place with full strength acetone. Nerve not cut. Wound closed. January 17, 1919, rabbit found dead in the morning; seemed in fairly good condition the day before, though somewhat emaciated. On exposing the right sciatic there is found no material increase in the connective tissue surrounding the nerve; central portion of the nerve adherent to underlying muscle. The main funiculi of the nerve evident practically the entire length. A slight increase in the diameter of the nerve is noted in the region of acetone injection. The calf muscles presented normal size and color; owing to death of animal could not be tested functionally. Sciatic removed and fixed in ammoniated alcohol or pyridine-silver staining. Good but faint differentiation attained.

Microscopic findings.—In three series of longitudinal sections, numerous both myelinated and nonmyelinated neuraxes, having in the main a longitudinal course, can be traced through the field of acetone injection. Scarcely any of the remains of the degenerated portions of nerve fibers found. In cross sections of the nerve, made just central to the place of acetone injection but in the region affected by the acetone, the funicular arrangement of the nerve trunk is found to be maintained. Within the several funiculi there is found a distinct increase of the endoneural connective tissue. So far as can be determined from histologic findings, very complete regeneration of the nerve distal to the place of acetone injection has taken place. Pieces of calf muscle were not removed for histologic study.

CONCLUSIONS

So far as can be determined from the limited number of experiments in which full strength acetone was injected into the nerve instead of absolute alcohol as in Series No. 1, this may be regarded as a safe procedure and affects the nerve in the region of the injection very much as does absolute alcohol. There is a "chemical section" of the nerve and the operation is followed by loss of function in the peripheral field of the respective nerve. In due time regeneration, through the region immediately affected by the acetone, takes place in a manner as after alcohol injection.

INJECTION INTO DIVIDED NERVE TO PREVENT AMPUTATION NEUROMA

SERIES NO. 3

INJECTION OF ABSOLUTE ALCOHOL INTO THE CENTRAL END OF A DIVIDED NERVE TO OBVIATE THE FORMATION OF AMPUTATION NEUROMA

SERIES NO. 4

AMPUTATION NEUROMA FORMATION IN ASEPTIC WOUNDS

The experimental observations here reported under Series No. 3 and No. 4 were undertaken with a view of studying the factors which cause and govern neuroma formation and if possible to devise a safe and practical method to prevent their formation, and to determine if possible the general principle according to which methods suggested to prevent neuroma formation might be judged critically on the basis of experimental observations. There has been abundant opportunity to study the neuroma formation in experimental operations other than those recorded under Series 4, since in many of the operations listed under other series, nerves were cut and resected incidental to the respective operation; this in experiments made on dogs as well as on rabbits. The work here reported was supplemented by further experiments, in which several of the methods suggested for the prevention of neuroma formation were tested experimentally. In these supplementary experiments, made post bellum, the operative work was done by Dean Lewis, in the animal laboratory of Rush Medical College, in affiliation with the University of Chicago, while the histologic study was undertaken by Huber at the University of Michigan. Their joint work formed the basis of a communication[63] dealing with the question of amputation neuromas, their development and their prevention, in which many of the experiments here listed under Series No. 3 and No. 4 were given consideration.

PROTOCOLS

Experiment No. 16.—Rabbit No. 24; large; full grown; 11 days. March 1, 1918, left sciatic exposed; large nerve. Absolute alcohol injected in several point injections; approximately 2.5 cm. of nerve well injected. Nerve cut distal to field of injection and resected about 1 cm. Wound closed. March 12, killed. Sciatic exposed. Distal end of central sciatic stump surrounded by a small amount of pus. Nerve ends in slight enlargement, having light yellow color. Hemorrhage into nerve trunk, extending for a distance of about 3 cm. from end. Central stump removed and fixed in neutral formalin. Tissue stained after the Bielschowsky silver staining method.

Microscopic findings. In several series of longitudinal sections, of successive levels of the distal end of the central sciatic stump, in the region affected by the injected alcohol the neuraxes of the nerve fibers are found in the form of short irregular segments. The myelin of the fibers is present in the form of a granular detritus and smaller and larger globules. The neurolemma sheaths appear well preserved. Here and there irregularly formed cellular elements are found within the neurolemma sheaths, the histogenesis of which is not clearly determined.

Experiment No. 17.—Rabbit No. 40; full grown; 18 days. March 5, 1918, left sciatic exposed and absolute alcohol injected; in the larger internal popliteal bundle several point injections. Quite a little absolute alcohol escaped into the wound. The nerve cut distal to the injection and resected. The wound closed. March 23, rabbit killed. Wound well healed. On exposing the sciatic no material increase of connective tissue about nerve. Distal end of central sciatic stump tapers to a fine point; slightly adherent to underlying muscle. About 2.5 cm. of end of central stump of light yellow color. Central sciatic stump removed and fixed in neutral formalin for Bielschowsky silver staining.

Microscopic findings.—In two series of longitudinal sections of successive levels of the distal end of the central sciatic stump it may be clearly ascertained that both of the main bundles of the sciatic were well injected, in that in practically all of the nerve fibers only scattered neuraxis fragments are to be found. The myelin remains found in the form of granular detritus. The neurolemma sheaths present, many showing spindle-shaped enlargement at irregular intervals. Small nuclei of doubtful source found scattered through the granular myelin detritus. The fibrous tissue sheaths of the distal end of the central sciatic stump thickened; fibrous tissue at the cut end of the nerve.

Experiment No. 18.—Rabbit No. 14; full grown; 20 days. February 26, 1918, left sciatic exposed and injected with absolute alcohol, making several point injections. Very little alcohol escaped to wound. Nerve cut distal to place of injection and resected 1 cm. Wound closed. March 18, rabbit found dead in the morning. Wound well healed. On exposing the sciatic, the distal end of the central stump found tapering to a fine line adherent to the underlying muscle. A small blood clot found surrounding the distal end of the central sciatic stump. Central sciatic removed and fixed in neutral formalin. Sections stained in iron hematoxylin and picro-fuchsin.

Microscopic findings.—In the several series of longitudinal sections made at successive levels, the structural appearance presented is such that the sections would not be recognized as sections of peripheral nerve tissue, endoneural connective tissue strands and neurolemma sheaths being the only portion of nerve structure recognized within the funiculi of the larger internal popliteal bundle. Within these sheaths, the neuraxes of the fibers have completely disappeared. The myelin remains are found in the form of a granular detritus or as inclusions in large vesicular cells having very small nuclei. In the external popliteal bundle, not so fully injected, certain normal fibers are to be found; other fibers showing degeneration phenomena, resembling those found in a peripheral nerve after section, are observed. The perineural sheaths of both the internal and external popliteal bundles present a structural appearance which is not unlike that of a normal nerve.

Experiment No. 19.—Rabbit No. 28; small; half grown; 21 days. March 1, 1918, left sciatic exposed and injected with aboslute alcohol; very successfully injected; hardly any alcohol escaped. Nerve cut distal to injection and resected. Wound closed. March 22, rabbit found dead in the morning; seemed well nourished; wound well healed. On exposing the left sciatic this found only slightly adherent to the muscle bed. Distal end of central stump, for about 1.5 cm. tapers to fine strand and is of light yellow color. Distal end of central stump removed and fixed in neutral formalin. Sections stained in iron hematoxylin and picro-fuchsin.

Microscopic findings.—In several series of longitudinal sections, including the area of alcohol injection, the perineural sheaths of the funiculi appear slightly thickened. Of the old nerve fibers, the neurolemma sheaths only in part present; areas in which they have disappeared. In such areas, and within distended neurolemma sheaths in other parts, there are found large vesicular cells, mutually compressed, having granular and globular inclusions. The cells have small nuclei. In the most distal part of the central stump such cells are less numerous, with a consequent reduction in the size of the nerve.

Experiment No. 20.—Rabbit No. 11; full grown; 24 days. February 26, 1918, left sciatic exposed and injected with absolute alcohol; cut distal to place of injection and resected. Wound closed. March 22, rabbit found dead in the morning; seemed well nourished; wound well healed. On exposing the nerve this was found only slightly adherent to the underlying muscle. Distal end of central stump presents tapering end. The central stump removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin.

Microscopic findings.—In series of longitudinal sections of the distal end of the central stump, including the area injected with absolute alcohol and 2 cm. central, perineural sheaths found well maintained. In the injected area, practically only the old neurolemma sheaths observed; many of these greatly distended, and here and there small areas where these have disappeared. In such areas and within certain of the neurolemma sheaths large vesicular cells with small nuclei are observed. Both of the main bundles equally involved.

Experiment No. 21.—Rabbit No. 1; large; full grown; 36 days. February 18, 1918, left sciatic exposed and raised from bed for several centimeters. Lifted on hook and injected with absolute alcohol. Area well injected presents a milky white appearance. Cut distal to injection and resected 5 mm. Wound closed. March 26, rabbit died during morning; still warm when found. Very much emaciated. Abscesses filled with "cheesy" pus in various parts of body. The wound was well healed. On exposing the nerve it was found that the external popliteal was not cut at the operation and apparently was not injected. The internal popliteal stump found with tapering end. Nerve fixed in neutral formalin. Bielschowsky silver staining; good differentiation of neuraxes.

Microscopic findings.—From a study of several series of longitudinal sections, it is evident that the external popliteal was insufficiently injected in that a large portion of this nerve bundle seems not to have been affected by the alcohol; showing normal nerve fibers. In the part of the nerve affected by the alcohol the neuraxes and myelin sheaths have disappeared and are replaced by a granular detritus and large vesicular cells with protoplasmic inclusions. Perineural sheaths not materially thickened.

Experiment No. 22.—Rabbit No. 21; full grown; 36 days. February 28, 1918, left sciatic exposed and injected with absolute alcohol; injected in two regions about 8 mm. apart. Nerve cut distal to field of injection and resected. Wound closed. April 5, rabbit found dead in the morning; emaciated; wound well healed. On exposing the nerve a discoloration about distal end of central stump noted (probably due to hemorrhage). The distal end of the central stump tapers to nearly a point and presents a light yellow color. About 1.5 cm. proximal to the distal end of central stump nerve presents a normal appearance. Nerve removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin.

Microscopic findings.—In three series of longitudinal sections taken at successive levels, including about 3 cm. of the distal end of the central stump, the following observations are permitted. Approximately 2 cm. central to the place of injection normal nerve tissue is reached. Distal thereto in progressive degree, neuraxes and myelin are replaced by granular detritus, globules and phagocytic cells, in part within neurolemma sheaths, in part in areas in which the neurolemma sheaths have disappeared, only strands of endoneural connective tissue remaining. Down-growing nerve fibers, in part with very thin myelin sheaths, can be traced from the central undegenerated portion into the degenerated area. These fibers are found singly or in small bundles; present a very regular course, with direction in the main parallel to the long axis of the nerve, and reach to within 1 cm. of the distal end of the central stump. Here and there strands of nucleated bands of syncytial protoplasm are noted in the degenerated portion of the nerve.

Experiment No. 23.—Rabbit No. 2; large; full grown; 49 days. February 18, 1918, right sciatic exposed; partly freed and injected with absolute alcohol; cut distal to injection and resected 5 mm. Wound closed. March 18, wound completely healed; hair growing over shaved area. April 8, found dead in the morning. On exposing nerve it was found that the external popliteal bundle was cut but not the internal bundle. External popliteal presents slight enlargement of distal end of central stump; end tapers to fine strand and is of light yellow color. Nerve removed and fixed in neutral formalin. Section stained in iron-hematoxylin.

Microscopic findings.—Only the cut external popliteal nerve sectioned. Evident from series of longitudinal sections that this branch was only partly injected, since in it only a small area in which neuraxes and myelin sheath distintegration is observed. The remainder of the stump resembles in structure closely amputation neuroma, with proliferation of connective tissue and down-growing neuraxes. This experiment can not be regarded as successful.

Experiment No. 24.—Rabbit No. 43; half grown; 52 days. March 5, 1918, left sciatic exposed and injected with absolute alcohol; one injection. Quite a little alcohol escaped to wound. Nerve cut and resected. Wound closed. April 25, killed. Rabbit in good condition. On exposing nerve, this presents normal appearance to about 2.5 cm. from distal end of the central stump. Distal end shows a slight spindle-shaped enlargement centralward, then tapers to a fine strand. Streaks of yellow-white color, parallel to long axis observed. The distal end of the central stump removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Miscroscopic findings.—In three series of longitudinal sections, taken at different levels, it may be observed, that in the distal part of the central stump to the extent of about 2 cm. the neuraxes and myelin and in part the neurolemma sheaths of the nerves have been replaced by granular and globular detritus and vesicular cells, arranged in columns or groups separated by strands of endoneural connective tissue and neurolemma remains. Single neuraxes or small groups of such, growing from the central undegenerated portion of the nerve can be traced into degenerated area. These neuraxes have a regular course, in the main parallel to the long axis of the nerve. Neucleated protoplasmic strands accompany these neuraxes. In the distalmost part of the central stump as yet no new neuraxes are found; from this part also the granular detritus and vesicular cells have disappeared.

Experiment No. 25.—Rabbit No. 22; full grown; 56 days. February 28, 1918, left sciatic exposed and injected with absolute alcohol; well injected. Nerve cut distal to field of injection and resected. Wound closed. April 25, killed. Rabbit in good condition; slight neurotrophic ulcer left foot. Wound well healed. On exposing nerve it is found that it presents a normal appearance to about 1.5 cm. from distal end of the central stump, which presents only very slight enlargement, is of yellow-white color, and tapers to fine strand, which seems continuous with surrounding connective tissue. Nerve removed and fixed in ammoniated alcohol for pyridine-silver staining. Successful silver differentiation attained.

Microscopic findings.—In series of longitudinal sections taken at successive levels it may be observed that numerous new neuraxes growing from the central undegenerated portion of the nerve have grown distally into the portion injected with absolute alcohol. These neuraxes course singly or in small bundles, having in the main a longitudinal course, the small bundles of neuraxes showing here and there interchange of fibers. Between these neuraxes are found columns or areas of granular detritus and vesicular cells. The down-growing neuraxes have practically reached the distal end of the central stump. There is observed no tangling or crisscrossing of neuraxes as seen in a neuroma, nor in the intergrowth of neuraxes and connective tissue as observed at the end of a neuroma.

Experiment No. 26.—Rabbit No. 41; large; full grown; 58 days. March 5, 1918, left sciatic exposed and internal and external popliteal bundles injected separately; the former two injections; well injected. Nerve cut distal to injection and resected 1 cm. Wound closed. May 3, rabbit found dead in the morning. Neurotrophic changes left heel; popliteal lymph gland enlarged. On exposing the nerve it is found that the central stump tapers to fine strand, and presents light-yellow color. About 2 cm. central to distal end of central stump nerve presents normal appearance, with funiculi distinct. Nerve removed and fixed in Flemming chrom-osmic-acetic solution. Sections stained in safranine and licht grün.

Microscopic findings.—In three series of longitudinal sections taken at successive levels it may be observed, beginning with the most distally placed series, that the neuraxes and myelin of the nerve fibers of both of the main funiculi have entirely disappeared, with fine strands of endoneural connective tissue and neurolemma sheath remains forming a very open meshed network, surrounding areas of granular and globular detritus, through which are scattered small round or oval nuclei. In the series of the next higher level the same

general structure is found for the greater part of the section. In the more central portion of the sections small strands of syncytial nucleated bands of protoplasm are observed, which become more numerous in the centrally placed of the three series. These nucleated protoplasmic bands have grown into the degenerated portion of the nerve from the central undegenerated portion.

Experiment No. 27.—Rabbit No. 38; nearly full grown; 63 days. March 5, 1918, left sciatic exposed; quite a little bleeding; controlled. Two injections of absolute alcohol made; both bundles injected. Nerve cut and 5 mm. resected. Wound closed. May 13, rabbit found dead in the morning; in fairly good condition. On exposing the nerve, distal end of central stump found tapering to fine strand slightly adherent to muscle bed. The distal end for a distance of about 2 cm. presents a light-yellow color; central to this nerve normal appearance. Nerve removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin.

Microscopic findings.—In several series of longitudinal sections taken at successive levels, it is observed that in the distal end of the central stump, in the area of the alcohol injection, neuraxes and myelin of the nerve fibers have entirely disappeared, fine strands of endoneural connective tissue and remnants of neurolemma sheaths remaining. This portion of the nerve consisting almost wholly of granular and globular detritus, surrounded by the perineural sheaths. More centralward in the series of sections, nucleated protoplasmic bands growing distally from the undegenerated central nerve are to be observed, to one side, near the perineural sheath, these protoplasmic bands extend distally to near the distal end of the central stump.

Experiment No. 28.—Rabbit No. 18; full grown; 65 days. February 27, 1918, left sciatic exposed; large vein cut; clamped. Absolute alcohol injected and nerve cut just distal to injected field and resected. Wound closed. May 5, found dead in the morning. Protocol incomplete, simple statement, "No neuroma."

Experiment No. 29.—Rabbit No. 10; full grown; 71 days. February 26, 1918, left sciatic exposed and injected with absolute alcohol. Nerve cut distal to field of injection; resected 1 cm. Wound closed. May 8, killed. Rabbit not in good condition; emaciated; "fungus" ears. On exposing, the left sciatic central stump is found ending in fine tapering strand, not especially adherent to the muscle bed; of light-yellow color. About 2 cm. central to distal end nerve presents the appearance of normal nerve. The nerve removed and fixed in ammoniated alcohol for pyridine-silver staining. Very good differential silver staining attained.

Miscroscopic findings.—From the microscopic appearances presented in the several series of longitudinal sections taken at successive levels, it is evident that the injection of alcohol was not wholly successful in this experiment. Numerous neuraxes may be traced from the central portion of the nerve, toward the end of the central stump, numerous large end-discs found at various levels. Especially to one side of the nerve, and about 2 mm. from its distal end, numerous complex spirals of neuraxes are to be observed. At the distal end of the central stump, crossing and recrossing of neuraxes is noted, though there is not observed that intergrowth of neuraxes and connective tissue as is generally seen in a neuroma. In the entire series of sections, few remains of myelin and neuraxes of the old nerve fibers observed. The conclusion seems warranted that at the time of operation the nerve trunk was partially injected with absolute alcohol, and that after section of the nerve a partial neuroma developed.

Experiment No. 30.—Rabbit No. 32; full grown; 80 days. March 4, 1918, left sciatic exposed. Several injections of absolute alcohol made, spaced at intervals of about 5 mm. Well injected. Nerve resected 1.3 cm. just distal to field of injection. Wound closed. May 23, killed. Rabbit in good condition; severe neurotrophic changes left hind foot. On exposing left sciatic, this presents a normal appearance to within 2 cm. of distal end of central stump. The end presents first a slight enlargement, then tapers to a fine strand only loosely adherent to the surrounding connective tissue. Distal nerve segment completely degenerated. Central sciatic removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Miscroscopic findings.—In three series of longitudinal sections and one series of cross sections approximately 3 cm. of the distal end of the central sciatic stump was sectioned. The most centrally placed sections include a portion of the normal nerve. Numerous downgrowing neuraxes may be traced from this portion of the nerve into that portion immediately influenced by the absolute alcohol. In this latter portion areas and columns of globular and granular detritus are found, coursing between which there may be observed smaller and larger bundles of neuraxes, which have in the main a regular course, with here and there interchange of fibers. These down-growing neuraxes may be traced to the distal end of the central stump, but present no tangling or intertwining as observed in a neuroma. The perineural sheath surrounds these down-growing neuraxes.

Experiment No. 31.—Rabbit No. 26; full grown; 83 days. March 1, 1918, left sciatic exposed and injected with absolute alcohol. Well injected. Nerve cut distal to field of injection and resected 8 mm. Wound closed. May 23, killed. Rabbit in good condition. On exposing the left sciatic, this presents normal appearance to within 2 cm. of distal end of central stump. Distal end of central stump presents slight enlargement, then tapers to fine strand, adherent to underlying muscles. Nerve removed and fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation attained.

Microscopic findings.—In two series of longitudinal sections in which approximately 4 cm. of nerve is sectioned, it is observed that numerous neuraxes growing distalward from the central uninjured portion of the nerve extend into the portion affected by the absolute alcohol. These neuraxes are inclosed within the thickened perineural and epineural sheaths and have in the main a longitudinal course, except those found in close proximity to the fibrinous sheaths; many of them cross and recross and intertwine on the inner surface of the perineural sheath. These down-growing neuraxes can be traced to the attenuated end of the central stump. The remains of the fibers affected by the absolute alcohol found in areas of granular detritus, interspersed with large vesicular cells and fat cells, between which course the neuraxes.

Experiment No. 32.—Rabbit No. 29; full grown; 83 days. March 1, 1918, left sciatic exposed and injected with absolute alcohol; well injected. Nerve cut distal to field of injection and resected. Wound closed. May 23, rabbit found dead in the morning. Left femur found broken; apparently some days before death. On exposing the sciatic, tissues about nerve found much congested and containing extravasated blood, owing to fracture. The distal end of the central sciatic found to taper to fine strand; relations not clear owing to extravasated blood. Nerve removed and fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation attained.

Microscopic findings.—In two series of longitudinal sections including approximately 4 cm. of the distal end of the promixal stump, large number of down-growing neuraxes may be traced from the uninjured central portion of the nerve to its distal end. These neuraxes are inclosed in the thickened fibrous tissue sheaths of the nerve and have in the main a regular course. Within the area injected with absolute alcohol a few columns and areas of granular detritus, certain large vesicular cells and many fat cells are found. Such columns and areas are separated by bundles of down-growing neuraxes, a few of which cross such fields either as single fibers or as small bundles of such.

Experiment No. 33.—Rabbit No. 17; nearly full grown; 84 days. February 27, 1918, left sciatic exposed and injected with absolute alcohol. First injection not successful; nerve slightly torn. Second attempt at a higher level, was successful; well injected. Nerve cut and resected. Wound closed. May 22, rabbit found dead in the morning; seemed in good condition; severe neurotrophic changes left hind foot. On exposing the left sciatic, the distal end of the central stump is found to taper to fine strand; adherent to the underlying muscle. Several delicate nerve bundles appear to extend on the muscle bed for a distance of about 1 cm. beyond the cut end of the nerve. No evidence of a neuroma noted. Nerve removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained. A portion of the nerve removed in this experiment was lost; the portion at hand represents the most distal portion of the central stump for the length of a little over 1 cm.

Microscopic findings.—In a series of longitudinal sections, small bundles of fine neuraxes inclosed within the thickened fibrous sheath are observed. These bundles of neuraxes are found separated by areas of granular detritus and fat cells.

Experiment No. 34.—Rabbit No. 42; half grown; 84 days. March 5, 1918, left sciatic exposed and injected with absolute alcohol; larger bundle in two stages; smaller bundle, one injection. Well injected. Nerve cut and resected 1 cm. Wound closed. May 29, rabbit found dead in the morning. Protocol incomplete. Nerve removed and fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation attained.

Microscopic findings.—In three series of longitudinal and cross sections in which approximately 4 cm. of nerve were cut, central neuraxes are found passing distalward through the area injected by absolute alcohol, and have reached the distal end of the central stump, and as scattered neuraxes or as small bundles of such can be traced into the connective tissue overlying the muscle bed for a distance of about 1 cm. beyond the cut end of the nerve. In the main these neuraxes have a very regular longitudinal course. Very little detritus, the remains of the injured nerve fibers found in the area injected with absolute alcohol.

Experiment No. 35.—Rabbit No. 8; full grown; 90 days. February 23, 1918, left sciatic exposed and injected with absolute alcohol; well injected. Nerve cut just distal to injection; resected 1 cm. Wound closed. May 23, killed. Rabbit very much emaciated; severe neurotrophic changes foot, two toes missing; large ulcer on heel. On exposing the sciatic, this is found of normal appearance to about 1.5 cm. from end of central stump. End of stump presents slight enlargement then tapers to a fine strand. The nerve removed and fixed in ammoniated alcohol for pyridine-silver staining. Faint but differential neuraxis staining attained.

Microscopic findings.—In three series of longitudinal and one of cross sections, taking in a little over 4 cm. of the distal end of the nerve the following may be observed: Neuraxes in large numbers can be traced from the central practically uninjured portion of the nerve, through the area affected by the alcohol to the distal end of the central stump. In a series of cross sections, taken about 2 cm. above the point of puncture for alcohol injection, the funicular structure of the nerve is not lost; the perineural sheaths are distinctly thickened. Within the funiculi, numerous neuraxes seen in cross section, four to ten within one neurolemma sheath. Not all of the funiculi found equally affected. In the more distal portion of the nerve, in two series of longitudinal sections, numerous neuraxes, having in the main a longitudinal course, and arranged in larger or smaller bundles, and separated by elongated areas and columns of granular detritus, vesicular cells and fat cells, are to be observed, inclosed within the thickened fibrous sheaths.

Experiment No. 36.—Rabbit No. 37; full grown; 93 days. March 5, 1918, left sciatic exposed and injected with absolute alcohol; both bundles well injected. Nerve cut about 5 cm. distal to place of injection and resected 1 cm. A small amount of alcohol escaped to wound. Wound closed. June 6, killed. Rabbit in fair condition; neurotrophic ulcer on left heel. On exposing the sciatic nerve is found to present normal appearance to near end of distal stump which tapers to a fine strand. Nerve removed and fixed in Flemming's chrom-osmic-acetic mixture. Sections stained in safranine and licht grün.

Microscopic findings.—In several series of cross and longitudinal sections made from the distal 4 cm. of the central stump the following observations are made: In the series of longitudinal sections small bundles composed of nucleated protoplasmic bands and fine myelinated nerve fibers may be traced from the central normal portion of the nerve to the end of the distal stump. Between these there are found broader or narrower columns composed of, in the main, large vesicular cells with small nuclei, having globular and granular protoplasmic inclusions. These cells would appear to have phagocytized the remains of the nerve fibers affected by the absolute alcohol. The fibrous sheaths of the distal end of the central stump are found materially thickened. In the distal 1.5 cm. the funicular structure of the nerve is lost.

Experiment No. 37.—Rabbit No. 34; full grown; 94 days. March 4, 1918, the left sciatic exposed and injected with absolute alcohol; well injected. Nerve cut 5 mm. distal to place of injection and resected 1 cm. Wound closed. June 5, killed. Much emaciated; severe neurotrophic ulcer, left heel. On exposing the left sciatic nerve found normal to within 1.5 cm. of end of the central stump; presents slight enlargement, then tapers to fine strand;

adherent to the underlying muscle. Nerve removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin. Tissue not well embedded, sections torn.

Microscopic findings.—In the sections remaining it can be determined that nucleated protoplasmic bands extend from the central undegenerated portion of the nerve to the distal end of the central stump. These bands of nucleated protoplasm regarded as nonmyelinated fibers. Between such bands or bundles are found columns or long spindle-shaped areas of large closely arranged vesicular cells with globular or granular inclusions.

Experiment No. 38.—Rabbit No. 39; small rabbit; not full grown; 95 days. March 5, 1918, left sciatic exposed; free venous bleeding. Absolute alcohol injected; larger bundle in several places; smaller bundle one injection. Well injected. A small amount of alcohol escaped to wound. Wound closed. June 8, rabbit found dead in the morning. On exposing the left sciatic this presents a normal appearance to within a short distance of the distal end of the central stump, which tapers to a fine strand. Nerve removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation is not successful.

Microscopic findings.—Several series of longitudinal sections, though not showing differentiation of neuraxes, are sufficiently stained to admit of making the interpretation that there was no neuroma formation; the arrangement of the connective tissue warrants this conclusion.

Experiment No. 39.—Rabbit No. 27; full grown; 97 days. March 1, 1918, left sciatic exposed and injected with absolute alcohol. On first attempt, movement of animal prevents successful injection; on second trial successful injection made. Nerve cut distal to injection and resected. June 6, killed. Rabbit in good condition. On exposing the left sciatic the nerve presents normal appearance to near distal end of the central stump, which appears to end in fine tapering strand. The relations of distal end of central stump not clearly made out owing to presence of dense cicatricial tissue at end of the fine tapering strand. Nerve removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good silver differentiation attained; sheath nuclei as well as neuraxes stained.

Microscopic findings.—Several series of longitudinal sections made. In these it is possible to trace numerous neuraxes from the more centrally placed sections, through the field affected by the alcohol injection to the distal end of the central stump. At the distal end of the central stump the neuraxes are found to cross and recross, especially those found in close relation to the outer fibrous sheath. In the more central portion the neuraxes present a more regular longitudinal course. In this portion of the nerve, between small bundles of neuraxes, large spindle-shaped areas composed of vesicular cells and granular detritus are to be found. In relation with the distal end of the central stump there was noted at the time the nerve was removed a small irregular mass about 5 mm. in diameter which appeared to consist of dense fibrous tissue. In sections this mass was found to contain a nucleus of osseous tissue surrounded by dense fibrous tissue. In this fibrous layer, mainly to one side, several small bundles of neuraxes were found. A study of this series of sections suggests imperfect alcohol injection, as a result partial neuroma formation, with proliferation of fibrous tissue consequent to escape of alcohol into the wound.

Experiment No. 40.—Rabbit No. 15; full grown; 102 days. February 26, 1918, left sciatic exposed and injected with absolute alcohol; nerve cut distal to injection and resected 1 cm. Wound closed. June 4, killed. Animal not in good condition; severe neurotrophic ulcer on left heel; popliteal lymph gland greatly enlarged. On exposing the left sciatic, the central stump found tapering to fine strand; distal end of light-yellow color. Connective tissue in proximal part of popliteal space quite dense. Central sciatic removed and fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation attained; especially more central portion of nerve.

Microscopic findings.—Two series of longitudinal sections, including the 2 cm. of the distal end of the central stump, made. In the more distally placed series, within the thickened fibrous sheath, a granular detritus and vesicular cells occupy nearly the entire area. No down-growing neuraxes appear to have reached this portion of the central stump. In the more centrally placed series, numerous new neuraxes are found; those more axially placed have a regular course; those more peripherally placed crisscross on the inner surface of the fibrous tissue but do not present the intergrowth of fibrous tissue and neuraxes as noted at the distal end of a neuroma.

Experiment No. 41.—Rabbit No. 3; large; full grown; 108 days. February 18, 1918, left sciatic exposed and injected with absolute alcohol. Nerve cut about 5 mm. distal to place of injection; not resected. Wound closed. June 6, killed. Left hind foot slight neurotrophic changes on heel. On exposing the sciatic it is found that the external popliteal was not cut, and probably not injected. Internal popliteal central stump presents a tapering end. Some delicate fine strands seem to extend beyond the cut end; on cutting of these "fibers," no twitching of calf muscles observed. The nerve removed and fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation attained.

Microscopic findings.—The noncut and noninjected external popliteal sectioned with the cut and injected internal popliteal, cut together in series of longitudinal sections. In the sections, the external popliteal presents the appearance of a normal nerve; here and there a few degenerated fibers are noted. In the distal end of central stump of the internal popliteal, central down-growing neuraxes can be traced to the distal end, having in the main a regular longitudinal course, and separated into smaller and larger bundles by long spindle-shaped areas, occupied by granular detritus and large vesicular cells. A few neuraxes can be traced into the connective tissue surrounding the distal end of the central stump of the internal popliteal.

Experiment No. 42.—Rabbit No. 25; half grown rabbit; 150 days. March 1, 1918, left sciatic exposed and injected with absolute alcohol. Well injected; practically no alcohol escaped to the wound. Sciatic cut 5 mm. distal to place of injection and resected 1 cm. Wound closed. July 30, killed. Rabbit not in good condition. On exposing the left sciatic the central stump is found to end in a fine tapering strand. No bulb. No nerve fibers could be traced beyond the cut end of the nerve. Central sciatic removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained. During embedding the end of the central sciatic stump became bent, so that it was not possible to cut longitudinal sections including the entire length of the piece.

Microscopic findings.—It is evident on study of the entire series, that down-growing neuraxes coming from the central uninjected portion of the nerve, have passed through the area injected with absolute alcohol and have reached the distal end of the central sciatic stump. These neuraxes have in the main a longitudinal course. Toward the distal end some crisscrossing of neuraxes is observed; not to the extent found in a neuroma, and such crisscrossing of neuraxes as is observed occurs within the fibrous tissue sheath and mainly on its inner surface.

Experiment No. 43.—Rabbit No. 23; nearly full grown; 157 days. March 1, 1918, left sciatic exposed and injected with absolute alcohol. Well injected. A small quantity of alcohol escaped to the wound. Nerve cut just distal to place of injection and resected. Wound closed. August 5, killed. Rabbit in good condition; foot missing; stump completely healed. On exposing the sciatic the central stump is found to end in fine tapering strand from the distal end of which a fine filament can be traced toward the distal sciatic stump, but does not reach it. Calf and foot flexor muscles completely degenerated. Central sciatic removed and fixed in ammoniated alcohol for pyridine-silver staining. Not wholly successful differentiation attained; patchy.

Microscopic findings.—In fairly complete series of longitudinal sections, taking in the distal 2 cm. of the central sciatic stump, it may be observed that numerous neuraxes, both myelinated and nonmyelinated, grow distal through the field of alcohol injection to the extreme distal end of the central stump. Here the connective tissue sheath of the nerve is found very materially thickened, the connective tissue extending into the interior of the nerve end and separating the nerves into small intertwining bundles. More centrally the neuraxes have a more regular longitudinal course, except those found in close relation to the fibrous tissue sheath, which course along the inner surface without definite arrangement. The structural appearances presented are not those of a neuroma.

The following eight experiments are briefly listed but not numbered:

Rabbit No. 30. Small rabbit; full grown; 1 day. March 1, 1918, left sciatic exposed; injected with absolute alcohol; cut; resected. Wound closed. March 2, found dead in the morning. On opening wound, evidence of hemorrhage along line of incision. Portion of

sciatic injected with alcohol of soft consistency; no gross hemorrhage into nerve. Tissue not sectioned.

Rabbit No. 45. Full grown; 7 days. March 5, 1918, left sciatic exposed; injected with absolute alcohol; large bundle in three stages. Nerve cut and resected. Wound closed. March 12, found dead. Reported too late to use tissue for microscopic study.

Rabbit No. 44. Nearly full grown; 8 days. March 5, 1918, left sciatic exposed; absolute alcohol injected. A small amount escaped to wound. Nerve cut and resected. Wound closed. March 13, a second operation attempted on right sciatic. Rabbit did not recover from second operation. Left sciatic wound found well healed. The distal end of the central sciatic stump found loosely adherent to the underlying muscle and presenting a slightly tapering end. Central sciatic removed and fixed in neutral formalin. Tissue lost in washing after fixation.

Rabbit No. 49. Half grown; 9 days. March 6, 1918, left sciatic exposed; injected with absolute alcohol. Nerve cut and resected. Wound closed. March 15, found dead in the morning. Reported too late to be used for microscopic study. Central end of sciatic found slightly tapering.

Rabbit No. 31. Half grown; 10 days. March 4, 1918, left sciatic exposed and injected with absolute alcohol. Nerve cut and resected. Wound closed. March 14, found dead in the morning. Must have been dead many hours. Wound well healed. Central sciatic stump found slightly tapering. Tissue not studied microscopically.

Rabbit No. 36. Full grown; 11 days. March 5, 1918, left sciatic exposed and injected with absolute alcohol. Nerve cut and resected. Wound closed. March 16, found dead in the morning. Rabbit dead many hours. Tissue not used for study. Central sciatic stump found slightly tapering.

Rabbit No. 19. Full grown; 93 days. February 27, left sciatic exposed and injected with absolute alcohol. Nerve cut and resected. Wound closed. June 1, rabbit found dead in the morning. Severe neurotrophic changes of left hind foot; secondary injection. On exposing the sciatic this is found to taper to fine strand. No neuroma. The tissue not studied.

Rabbit No. 30. Full grown; 98 days. February 28, 1918, left sciatic exposed and absolute alcohol injected. Wound closed. June 6, rabbit found dead in the morning. Reported too late to be of use in study of the tissue. On exposing the nerve this is found to taper to a fine strand. No neuroma.

Experiment No. 44.—Rabbit No. 28a; small; half grown; 9 days. March 13, 1918, right sciatic exposed; cut and resected 1.2 cm. Wound closed. March 22, rabbit found dead in the morning. Wound well healed. On exposing the sciatic, a small swelling on the distal end of central sciatic stump noted. Beginning of neuroma. Central sciatic stump removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin.

Microscopic findings.—In longitudinal sections of the distal end of the central stump early stages of amputation neuroma formation noted, evidenced structurally by fragmentation of the myelin to the extent of about 8 mm. of the distal end of the central nerve fibers; proliferation of the sheath cells in this region; proliferation of the connective tissue.

Experiment No. 45.—Rabbit No. 12; full grown; 25 days. February 26, 1918, left sciatic exposed; cut and resected. Wound closed. March 23, killed. Wound healed. On exposing nerve a distinct bulb on distal end of the central sciatic stump found. Removed and fixed in ammoniated alcohol for pyridine-silver staining. Tissue misplaced; not sectioned.

Experiment No. 46a.—Rabbit No. 16; small rabbit; not full grown; 28 days. February 26, 1918, left sciatic exposed; cut and resected. Wound closed. March 26, killed. Rabbit in good condition. On exposing the left sciatic distinct bulb found on central end of the distal stump. A delicate filament, having the appearance of a small nerve, traced a short distance beyond the distal end of the nerve bulb. Bulb removed and fixed in neutral formalin for silver staining. Bielschowsky silver method used.

Microscopic findings.—In longitudinal section it is noted that the neuraxes were not differentially stained, but that the fibrous tissue is very clearly differentiated. This enables

the observation that in a neuroma the endoneural connective tissue as well as the perineural sheaths show distinct proliferation.

Experiment No. 46b.—Rabbit No. 4; full grown; 34 days. February 19, 1918, left sciatic exposed; cut and resected. Wound closed. March 26, killed. Wound well healed. On exposing the left sciatic a long spindle-shaped enlargement is found on the distal end of the central sciatic stump, from which is seen to pass a fine nerve bundle, lost in the connective tissue a short distance distal to the bulb. Central sciatic and bulb removed and fixed in neutral formalin for Bielschowsky's silver staining method.

Microscopic findings.—In longitudinal sections of the distal end of the central stump amputation neuroma evidenced structurally; branching of down-growing neuraxes, many ending in terminal disks; neuraxes with irregular serrated borders; neuraxes showing spiral arrangement are observed; endoneural connective tissue proliferated.

Experiment No. 47.—Rabbit No. 47; full grown; 35 days. March 6, 1918, left sciatic exposed; cut and resected 2 cm. Wound closed. April 10, rabbit found dead in the morning; severe neurotrophic changes of heel; wound well healed. Nerve not exposed until about 18 hours after death. Central sciatic stump found to end in distal spindle-shaped bulb. Central sciatic and bulb removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin.

Microscopic findings.—In a series of longitudinal sections of the distal end of the central sciatic stump, neuraxes coming from the distal end of the bulbous enlargement can be traced into the connective tissue distal, in the form of small myelinated fibers, either singly or in small bundles. These have a very irregular course in the connective tissue and extend for a distance of about 3 mm. beyond the end of the bulb. A distinct mass of connective tissue, blending the internal and external popliteal bundles and extending through the bulb region centralward, is found to contain many small bundles of nerve fibers. There is found a distinct increase in the thickness of the connective tissue sheaths in the bulb region, and also of the endoneural connective tissue.

Experiment No. 48.—Rabbit No. 22a; full grown; 44 days. March 13, 1918, right sciatic exposed; cut and resected 1.5 cm. Wound closed. April 25, killed. Wound well healed. On exposing the right sciatic its central stump found to end in a long spindle-shaped bulb adhering to the underlying muscle. Nerve and bulb removed and fixed in ammoniated alcohol for pyridine-silver staining. Very good differential silver staining attained.

Microscopic findings.—In removal of the distal end of this nerve there was removed with it a portion of underlying fascia and muscle; in the serial longitudinal sections these tissues are included in normal relation. In study of the series of sections it is found that down-growing neuraxes have grown distally beyond the limits of the bulbous enlargement, and after passing a tangled irregular course in the connective tissue penetrate the underlying fascia, and in smaller and larger bundles extend distally between muscle fibers in quite regular longitudinal course for a distance of at least 1 cm., the distal limits of the section. Certain of these neuraxes are found to end abruptly in terminal discs, these often showing branching, so that two or three discs are found at the distal end of one neuraxis. Within the bulbous enlargement marked increase in number of neuraxes is noted.

Experiment No. 49.—Rabbit No. 10a; full grown; 57 days. March 12, 1918, right sciatic exposed; cut and resected 1.8 cm. Wound closed. May 8, killed. Rabbit much emaciated; "fungus" ears. On exposing the right sciatic its central stump is found to end in a distinct bulbous enlargement, from the distal end of which several fine nerve bundles, spreading out fan-shaped, can be traced for a short distance on the fascia overlying the muscle. Nerve and bulb removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—In a series of longitudinal sections neuroma structure is evidenced by the great increase in the number of down-growing neuraxes, and their irregular crisscross course at the level of nerve section. Numerous small bundles of neuraxes traced into the connective tissue distal to the bulbous enlargement; these are lost in the connective tissue.

Experiment No. 50.—Rabbit No. 17a; nearly full grown; 71 days. March 12, 1918, right sciatic exposed; cut without lifting from bed; resected 1.5 cm. Wound closed. May

22, rabbit found dead in the morning. On exposing the right sciatic its central stump found to end in a distinct bulbous enlargement, not adherent to the underlying fascia and muscle. Nerve and bulb removed and fixed in ammoniated alcohol for pyridine-silver staining. Only fair differential silver staining attained.

Microscopic findings.—In section, sufficient neuraxes staining found to determine neuroma structure; few neuraxes have grown distally beyond the limits of the neuroma.

Experiment No. 51.—Rabbit No. 60; full grown; 79 days. March 12, 1918, left sciatic exposed; nerve cut and resected 0.6 cm. Not resected. Wound closed. May 31, rabbit found dead in the morning; severe neurotrophic changes in left hind foot. On exposing the left sciatic, no distinct bulbous end noted on distal end of central stump, in place of bulb a long spindle-shaped enlargement from the distal end of which several fine nerve bundles can be traced to the central end of the distal sciatic stump, which end is slightly enlarged. Sciatic removed and fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation attained.

Microscopic findings.—In several series of longitudinal sections including the central and distal resected nerve ends and the intervening connective tissue, it can be observed that when structurally considered there is present a well-developed amputation neuroma. Many neuraxes spirals are found, with evidence of great increase in the number of neuraxes. In the region representing the central cut end of the nerve, neuraxes in smaller and larger bundles intertwine with bundles of fibrous tissue; certain of the neuraxes bundles extend distally in the connective tissue, and may be traced to the central end of the distal stump; others can be traced to the underlying muscle, between muscle fibers of which they course.

Experiment No. 52.—Rabbit No. 34a; full grown; 84 days. March 13, 1918, right sciatic exposed; cut and resected 1.3 cm. Wound closed. June 6, killed. Severe neurotrophic changes right foot. On exposing the right sciatic, its distal end is found to end in a distinct, long, spindle-shaped bulb, from the distal end of which several small nerve bundles can be traced to the central end of the distal sciatic stump. The central bulb and these nerve strands not adherent to the underlying muscle. No contraction of the calf muscles observed on cutting nerve central and then distal to place of sciatic resection. Sciatic removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation good for the more centrally placed series of sections; for more distal series, incomplete.

Microscopic findings.—In longitudinal sections of the central bulb region amputation neuroma evidenced structurally from the distal end of which many small bundles of neuraxes can be traced into the connective tissue intervening between the resected nerve ends. In cross sections of this connective tissue area numerous small bundles of neuraxes, cut in cross, oblique or, for a distance, in longitudinal section, are found separated by connective tissue. In longitudinal sections of the central end of the distal sciatic stump the silver differentiation not wholly successful, sufficient neuraxes staining observed to warrant the conclusion that certain of the central neuraxes have reached the distal sciatic stump through the connective tissue intervening between the resected nerve ends.

Experiment No. 53.—Rabbit No. 46; full grown; 85 days. March 6, 1918, left sciatic exposed; cut and resected 2 cm. Wound closed. May 31, rabbit found dead in the morning; slight neurotrophic changes in the left foot. On exposing the left sciatic very distinct bulbous ends on both the main branches noted; these bulbs taper distalward into fine nerve strands which can be traced a short distance beyond the nerve bulbs. Central sciatic and bulbous enlargement fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—In a series of longitudinal sections of the central bulbous enlargement amputation neuroma evidenced structurally; many spirals of neuraxes found, numerous branching neuraxes and terminal end-discs noted. Relatively few neuraxes can be traced into the connective tissue distal to the bulb.

Experiment No. 54.—Rabbit No. 15a; large; full grown; 87 days. March 13, 1918, right sciatic exposed; cut and resected 1.5 cm. Wound closed. June 8, killed. Severe neurotrophic changes of right foot. On exposing the right sciatic distinct bulbous enlargement on distal end of central sciatic stump found. A fine strand of nerve fibers can be traced from the distal end of the central bulb to the central end of the distal sciatic stump.

Sciatic removed and fixed in ammoniated alcohol for pyridine silver staining. Good silver differentiation attained.

Microscopic findings.—In sections a large amputation neuroma evidenced structurally; in this noted spirals of neuraxes, end-discs, crisscrossing of neuraxes, especially at its distal end. Relatively few neuraxes can be traced to the connective tissue distal to the neuroma. The distal sciatic degenerated; no evidence of regeneration.

Experiment No. 55.—Rabbit No. 35; full grown; 93 days. March 4, 1918, left sciatic exposed; cut and resected 1 cm. Wound closed. June 5, rabbit found dead in the morning. On exposing the left sciatic the distal end of the central stump presents a well-formed, relatively large bulbous end. Several fine nerve strands traced a distance beyond the bulb; lost in the connective tissue. Sciatic removed and fixed in ammoniated alcohol for pyridine-silver staining. Unfortunately tissue lost; not sectioned.

Experiment No. 56.—Rabbit No. 25a; half grown; 129 days. March 20, 1918, right sciatic exposed; cut and resected 1.2 cm. Ends of cut sciatic placed in alignment, and muscles sutured over them. Wound closed. July 30, killed. Rabbit not in good condition. On exposing the right sciatic the central stump is found to end in a long spindle-shaped bulbous end, the distal end of which reaches the central end of the distal sciatic stump; the nerve bundles uniting the resected nerve ends is adherent to the underlying muscle. The distal sciatic stump presents a spindle-shaped enlargement nearly as large as that found on the central sciatic stump. Sciatic nerve removed and fixed in ammoniated alcohol for pyridine-silver staining. Only partial differential staining attained.

Microscopic findings.—In series of longitudinal sections, well-developed amputation neuroma evidenced structurally, from the distal end of which larger and smaller bundles of neuraxes can be traced to and through the connective tissue intervening between the resected nerve ends. In the central end of the distal sciatic stump relatively large numbers of neuraxes observed in such portions of the series of sections in which the silver differentiation is sufficiently good to determine them.

Experiment No. 57.—Rabbit No. 13; full grown; 160 days. February 26, 1918, left sciatic exposed; cut and resected 1 cm. Wound closed. August 5, killed. Much emaciated; left foot missing; healed over. On exposing the left sciatic a distinct bulbous end on the distal end of the central sciatic stump noted, from the distal end of which fine nerve strands can be traced toward the central end of the distal sciatic stump, but do not appear to reach it. Calf muscles found atrophic. Central sciatic and bulb fixed in ammoniated alcohol for pyridine-silver staining; distal internal popliteal fixed in neutral formalin. Only fair differential silver staining attained.

Microscopic findings.—Well-developed amputation neuroma evidenced structurally, from the distal end of which only a few neuraxes can be traced into the connective tissue distal to the neuroma. The nerve fibers of the distal internal popliteal found completely degenerated; relatively few nuclei observed; neurolemma sheaths found thickened and collapsed.

Experiment No. 58.—Rabbit No. 58; full grown; 179 days. March 12, 1918, left sciatic exposed and cut high in thigh; the cut ends retracted so as to be separated 8 mm. Wound closed. September 8, killed. Rabbit in fairly good condition; somewhat emaciated; "fungus" ears. On exposing the left sciatic there is observed a spindle-shaped enlargement on the central sciatic stump, the distal end of which continues to the central end of the distal sciatic stump, the intervening bundle being of nearly the same size as the sciatic. The distal sciatic presents the appearance of a normal nerve. The distal end of the central bulb, as also the intervening nerve bundle, presents a light red color as though more vascular than the remainder of the nerve. The sciatic and a segment of the internal popliteal and posterior tibial fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin.

Microscopic findings.—In longitudinal sections of the central bulb it is seen that numerous nerve fibers, both myelinated and nonmyelinated, pass from the distal end of the bulb into the connective tissue. Of these, those coming from the more axial portion of the bulb have in the main a longitudinal direction, while those which come from the more peripheral portion of the bulb present a very irregular course. In the central end of the distal stump and

at levels to the middle of the leg in the posterior tibial, in cross sections, numerous myelinated nerve fibers are to be seen.

Experiment No. 59.—Rabbit No. 57; full grown; 180 days. March 12, 1918, left sciatic exposed and cut high in thigh; ends retracted so as to be separated 6 mm. Muscles stitched over cut nerve ends. Wound closed. September 9, rabbit found dead in the morning; left foot missing; stump healed. On exposing the sciatic a nerve bundle of a diameter nearly as large as the sciatic extends from a central sciatic bulb to the distal sciatic stump. The distal sciatic presents the appearance of a normal nerve. Sciatic removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht-grün.

Microscopic findings.—In longitudinal sections of the central bulb region numerous nerve fibers arranged in small bundles can be traced from the distal end of the central bulb into the connective tissue distal to the bulb. In cross sections of the nerve bundle intervening between the resected nerve ends, it is observed that the nerve fibers are arranged in numerous small funiculi, having no definite perineural sheaths and separated by intervening connective tissue. In the distal sciatic stump, in both cross and longitudinal sections, numerous myelinated fibers are observed among fibers not yet regenerated.

Experiment No. 60.—Rabbit No. 51; full grown; 10 months. March 11, 1918, left sciatic exposed, cut high in thigh; ends retracted 7 mm. Wound closed. January 9, 1919, rabbit seemed normal 4 p. m.; found dead 9 p. m.; still warm. Toes of left foot found missing; healed. On exposing the left sciatic, except for slight central enlargement and loss of the funicular structure in the region of the nerve section, sciatic nerve presented the appearance of a normal nerve. Calf muscles and foot extensors seemed fully regenerated. Sciatic removed and fixed in ammoniated alcohol for pyridine-silver staining. Faint but differential silver staining attained.

Microscopic findings.—In longitudinal sections of the bulbous enlargement on the central sciatic stump the neuroma structure evidenced by the crisscrossing of the neuraxes and loss of the funicular structure of the nerve. In cross sections of the tissue intervening between the resected nerve ends, numerous small funiculi of both myelinated and non-myelinated nerve fibers, separated by bands of fibrous tissue are observed. In a series of longitudinal sections embracing the central end of the distal stump, both myelinated and nonmyelinated nerve fibers, with regular order of direction are found in the connective tissue over the end of the distal stump and can be traced into the distal nerve in which they assume a definite longitudinal course.

Experiment No. 61.—Rabbit No. 53; nearly full grown; 11 months. March 11, 1918, left sciatic exposed and cut; ends retracted 5 mm. Wound closed. January 17, 1918, rabbit found dead in the morning; somewhat emaciated. On exposing the left sciatic the nerve is observed to present two spindle-shaped enlargements about 2 cm. apart, in the region of the nerve section. These are found united by a nerve bundle of about the same size as the sciatic. In the region of the two enlargements and the intervening bundle the nerve adherent to the underlying muscle. Calf and extensor foot muscle seem regenerated; presenting normal size and color. The animal was found dead too long after death to make tissue of much value for special differential neuraxes staining. Fixed in ammoniated alcohol for pyridine-silver staining. Imperfect differentiation attained.

Microscopic findings.—Sufficient silver differentiation of neuraxes obtained to determine in several series of longitudinal sections that both myelinated and nonmyelinated nerves coming from the central bulb, passing through the intervening connective tissue, have reached the distal sciatic.

Experiment No. 62.—Rabbit No. 55; large; full grown; 1 year. March 11, 1918, left sciatic exposed and cut high in thigh, end retracted 8 mm. Very little bleeding. Muscle stitched over nerve. Wound closed. March 11, 1919, killed. Active, in good condition; left foot missing; healed. On exposing the left sciatic two slight, spindle-shaped swellings are observed about 1 cm. apart, the distance bridged by a nerve bundle nearly the size of the sciatic; this in the region of nerve section. In this region nerve is adherent to the underlying muscle. On exposing calf and foot extensor muscles, these present a normal appearance. On cutting nerve near sciatic notch, vigorous contractions of calf and foot extensor muscles noted; the same on cutting nerve in the popliteal space. Sciatic fixed in ammoniated alcohol

for pyridine-silver staining; portions of calf muscles stained in gold chloride. Very good silver differentiation attained.

Microscopic findings.—In longitudinal sections of the central bulb numerous myelinated and nonmyelinated nerve fibers are seen to cross and recross in the distal end of the central bulb and enter the connective tissue intervening between the resected nerve ends. In cross sections of the field a large number of small nerve funiculi, without special fibrous sheaths but separated by bands of fibrous tissue, can be observed. In longitudinal sections of the distal end of the central sciatic small nerve bundles with very sinuous course can be traced from the connective tissue into the distal sciatic in which the neuraxes assume a regular longitudinal course. Cross and longitudinal sections of the distal sciatic at several levels present an appearance which resembles closely that of a normal nerve. Differentiation of nerve and endings in the muscle not successful.

Experiment No. 63.—Rabbit No. 56; full grown; 1 year. March 11, 1918, left sciatic exposed; cut high in thigh; cut ends retracted 8 mm. Very little bleeding. Muscle stitched over nerve. Wound closed. March 11, 1919, killed. Rabbit in good condition. On exposing the sciatic the two resected ends found united, without appreciable enlargement of the central or distal resected ends. Calf and foot extensor muscles present normal appearance and contract vigorously when nerve is cut central and distal to the region of section. Sciatic removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—In series of cross and longitudinal sections, including the field of operation and the nerve distal, it can be observed that numerous neuraxes coming from the distal end of the central bulbous enlargement pass through the connective tissue intervening between the resected nerve ends and enter the distal sciatic, in which they are found in large numbers in all of the funiculi. In cross section of the connective tissue found between the resected nerve ends the neuraxes, both myelinated and nonmyelinated, are found in the form of numerous small nerve funiculi, separated by bands of connective tissue.

For more than a century consideration has been given to the swellings which form on the distal end of the proximal stump of a completely or partially severed nerve and known as neuroma or neuromata. The literature dealing with the structure of neuroma is quite extensive and the surgical literature dealing with the operative means for the prevention of neuroma formation covers a period of many years. The histologic description of neuroma, presented by various writers, differs widely, especially for the period preceding the introduction of specific neuraxis stains. It is not thought necessary to review here at length this extensive literature; certain of the more pertinent references will be given incidental consideration.

The operations reported upon under Series No. 4 were made under strictly aseptic precautions and with as little bleeding as possible, hemorrhage and suppuration having been looked upon as important causative factors in neuroma formation. The structural changes observed in the distal end of the proximal stump of a divided nerve, severed by means of a sharp instrument placed in an aseptic wound, are, during the first few days after the operation, precisely the structural changes observed in the distal end of the proximal stump of a severed nerve, immediately sutured under aseptic conditions. For a distance of from 5 mm. to 1 cm. from the cut surface, both myelinated and nonmyelinated nerve fibers show degenerative changes accompanied by proliferation of sheath cells, comparable in every way to the degenerative changes noted in the peripheral stump. The abortive regenerative changes, considered in the general introduction, may also be observed. The connective tissue of the nerve trunk early shows reaction to the injury, evidenced by cell proliferation

in the region of the cut surface and exudate covering it, so that the cut end of the nerve is early covered by a connective tissue cap which becomes continuous with the epineurium of the nerve and less with the surrounding tissue. This connective tissue cap occurs quite regularly in neuromas. It is found organiz-

FIG. 218.—A longitudinal section of a typical neuroma removed from the sciatic of a dog 31 days after section; pyridine-silver preparation. The relations of the epineurium and the connective tissue cap found on the end of the neuroma are clearly seen. Note the regular arrangement of the nerve fibers and neuraxes in the upper half of the figure and the crisscrossing and otherwise irregular arrangement of the neuraxes as evident in the lower half of the figure

ing when the central neuraxes show the early evidences of regeneration and downgrowth. These evidences of regeneration, as concerns the neuraxes, are best seen and studied in silver preparations, and consist of end and side branches of neuraxes often found terminating in end-discs, very much as observed in regeneration of a severed nerve and subsequent suture. There is distinct

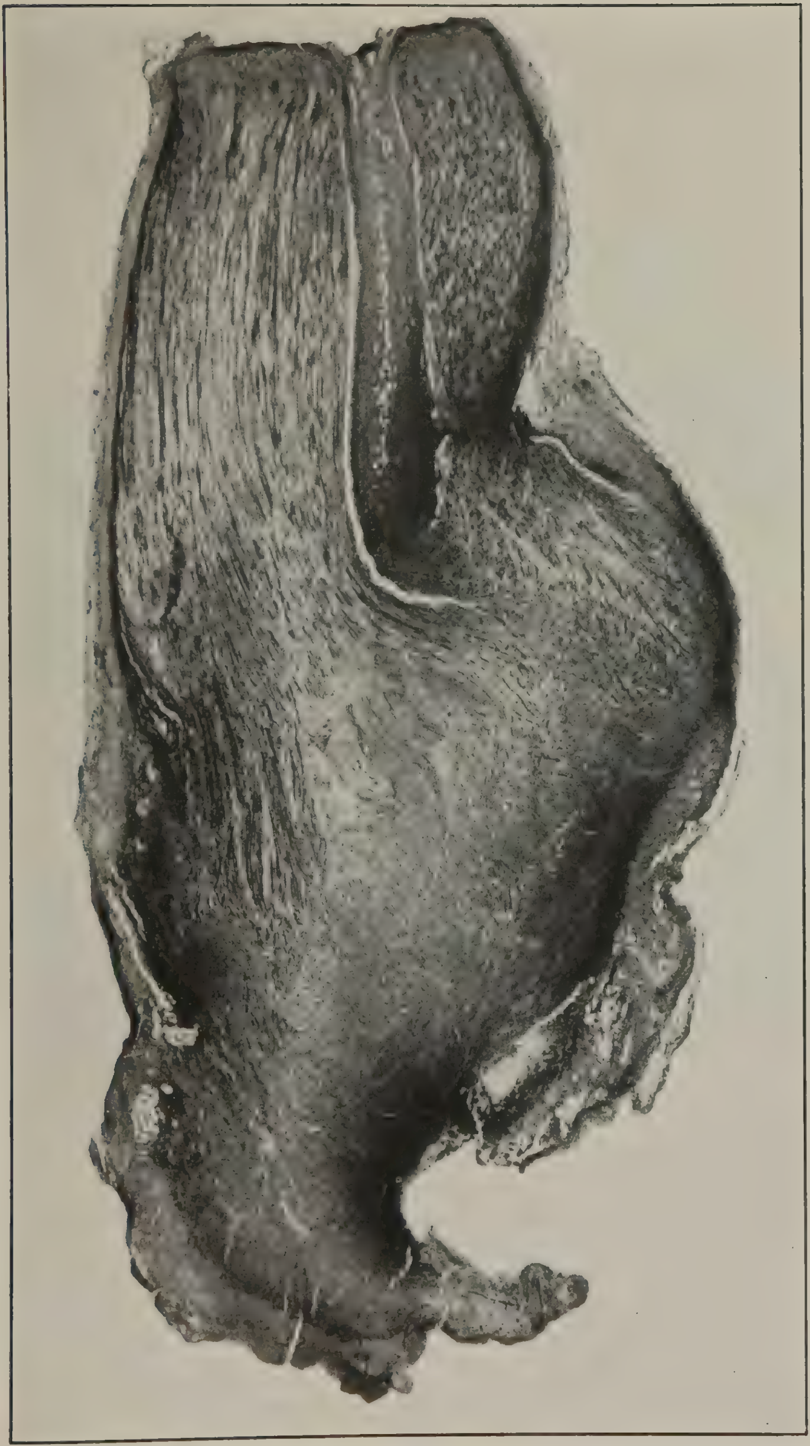

FIG. 219.—Longitudinal section of an atypical neuroma from the sciatic of a dog, 18 days after section; pyridine-silver preparation. The general structure of the neuroma is clearly evident. The atypical form was due to pressure consequent to scar tissue formation

evidence of sheath cell proliferation, but their relation to the budding and growing neuraxes is not quite clear in silver preparations nor can they be definitely differentiated from the proliferating connective tissue cells. During the second week after resection of the nerve, neuraxis budding and downgrowth is clearly demonstrable. The down-growing neuraxes approach the region of neuroma formation with fairly regular and approximately parallel course; as they approach the region of the fibrous cap, single neuraxes or small bundles of such begin to intertwine; many are deflected from their course, even to the extent of turning centralward, and many terminal end-discs are observed. There is fairly distinct interlacement of organizing connective tissue bundles. Very characteristic of the earlier stages of neuroma formation are peculiar spiral complexes, first described by Perroncito, and formed of a single relatively large neuraxis or several neuraxes in axial position, about which are wound in spiral form a variable number of neuraxes and their branches, many ending in end-discs and all found within a neurolemma sheath. These Perroncito spirals may be scattered singly here and there or be found in larger or smaller groups. As such a spiral grows in diameter it would seem that the old neurolemma sheath disappears so that the spirals come to lie in the endoneural connective tissue. The connective tissue of a neuroma is deserving of consideration. It is composed of loosely woven, wavy, connective tissue bundles, is quite cellular and differentiates quite slowly into a compact tissue. One gains the impression that the growing neuraxes, as they reach the region of the connective tissue cap and the sides of the growing neuroma, for some time stimulate connective tissue to growth. The formation of the central budding and growing neuraxes and the connective tissue of the neuroma progress simultaneously and there develops an intergrowth of connective tissue and neuraxes which characterize the terminal part of the neuroma. A neuroma is to be regarded as a thwarted attempt at regeneration of the nerve, the down-growing neuraxes being blocked by scar tissue. In many instances a well developed neuroma has formed in a strictly aseptic wound by the end of the third or the beginning of the fourth week after operation. As time progresses, in many instances, neuraxes singly or in small bundles, penetrate the cap over the end of the neuroma and penetrate the surrounding connective tissue, pass into intermuscular septa and may penetrate adjacent muscle and course between muscle fibers. In course of time, the down-growing neuraxes may reach the central end of the distal stump and bring about at least partial neurotization of the distal segment. The importance of the participation of growing and budding central neuraxes in neuroma formation, is clearly seen in pyridine-silver preparations of suitable stages. Cone [64] has stressed the fact that three-fourths of each painful bulb consists of nerve fibers and we are led to think that their proliferation against resistance is a cause of pain. All neuroma in the earlier stages of development consist, to a large extent, of nerve fibers or of neuraxes and in all neuromata there is to be noted proliferation of neuraxes against resistance. This fact led us to feel that any measure employed with a view of preventing neuroma formation, in order to attain success, must be directed primarily toward the neuraxes and not the connective tissue of the severed nerve end. Huber and Lewis [63] tested experimentally

several methods recommended in clinical surgery and directed more particularly toward the connective tissue at the end of the severed nerve, such as "swing door operation" and "crush and tie," and under most favorable conditions of asepsis, neuroma formation was accentuated rather than obviated. In the experiments in which absolute alcohol was injected in the nerve, the procedure was directed toward the neuraxes and it was hoped distinct delay in neuraxis downgrowth would be attained. It may be stated that the escape of a few drops of alcohol, an accomplishment more likely to occur while injecting a nerve the size of that of the sciatic of rabbit, than the larger nerves of the extremities of man, is not to be regarded as of serious consequence, since the records show that the escape of absolute alcohol into the wound was not followed

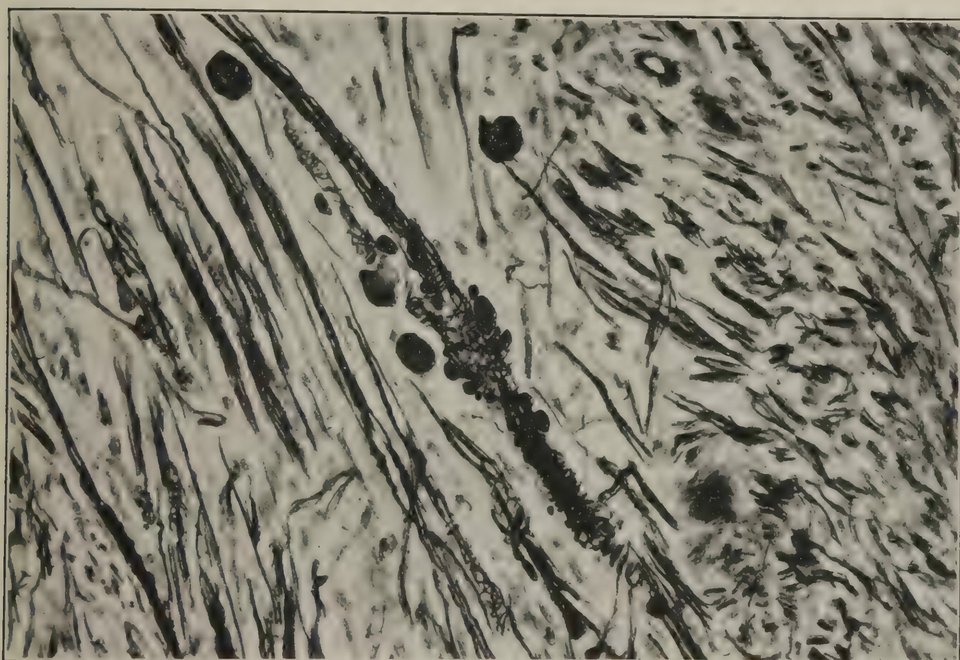

Fig. 220.—Spiral formations of neuraxes from neuroma shown in Figure 219. The figure presents a number of end-discs, certain of which are the terminations of neuraxes participating in the spiral structures

by excessive scar tissue formation. One can not agree, therefore, with Corner [65] who states that "injection of alcohol, quinine, and urea should not be used, as about three or four fifths of an injection flows out of a nerve into the surrounding tissue, causing later large formation of scar tissue round the nerve and subsequent strangulation."

The procedure employed in the experiments listed under Series No. 3 was to inject the central stump of a resected nerve approximately 1.5 cm. from the cut surface with absolute alcohol, through a hypodermic needle, inserting the needle very obliquely and centralward. Enough alcohol was slowly injected to give the nerve in the region of the injection and for a distance of approximately 2 cm. a milk white appearance or the appearance of cooked white of egg. If alcohol escaped into the wound, this was taken up with sterile cotton

and the wound closed. At the end of stated periods the operated nerves were removed and studied macroscopically and microscopically as detailed in the protocols of the several experiments of Series No. 3.

SUMMARY

From a study of the protocols of the series it may be noted that as a consequence of alcohol injection there ensues a fragmentation of the neuraxes and a granular breaking down of the myelin sheaths, and a destruction of the sheath cells in the region of the alcohol injection while the fibrous tissue sheaths and the endoneural connective tissue are not affected to the extent of losing their fibrillar structure. These changes affect a region of approximately 2 cm. in the nerves experimented with, namely, the sciatic of rabbits. There is then in the distal portion of the proximal stump thus treated no neuraxis regeneration nor fibrous tissue proliferation of the tissue under consideration. By the end of the third week and the beginning of the fourth week, the fragments of the old neuraxes have disappeared as also much of the myelin detritus. The old neurolemma sheaths seem to persist, and large vesicular cells, many with relatively small nuclei, and having lipoid granules and globules in their protoplasm, the histogenesis of which it is difficult to determine in the pyridine-silver preparations, make their appearance. They are wholly unlike the hypertrophied sheath cells of degenerating nerves. A resected nerve without alcohol injection, or with "swing door" or "crush and tie" operation after resection, shows by the end of the first month after operation a well-developed neuroma. Beginning with the fifth or sixth week after operation, a down-growth of central neuraxes into the region affected by the alcohol begins to be noted. The down-growing neuraxes, as observed in pyridine-silver preparations, in longitudinal section present a fairly regular course in the main parallel to the long axis of the nerve. They appear to course, in part at least, within old neurolemma sheath remains (or sheath of Henle) and gradually reach the distal end of the proximal stump by the end of the second or the middle of the third month after operation. The down-growing neuraxes are accompanied by sheath cells, it is thought derived from central sheath cells. Even in nerve ends seen four to five months after resection and injection of alcohol there is no evidence of neuroma formation, although central neuraxes, both myelinated and nonmyelinated, have passed through the injected portion of the nerve to the extreme distal end of the proximal segment. The connective tissue sheaths of this region are distinctly thickened and the endoneural tissue increased so that the nerve fibers found in the distal end are seen in small interlacing and intertwining bundles, separated by connective tissue. In none of the nerves studied in this series was there any distinct evidence of neuroma formation except in cases in which alcohol injection was not successful.

As a result of observations on experiments of Series No. 3 and No. 4, evidence at hand warrants the statement that a neuroma indicates an attempt at nerve regeneration which is thwarted by the formation of scar tissue found at the end of the neuroma; that they form in aseptic wounds and their formation is in no sense dependent on the presence of blood clot or infection resulting in suppuration. We believe ourselves to have demonstrated that absolute

alcohol injected into the nerve, 2 cm. to 2.5 cm. from its cut surface in several point injections arranged so as to involve all parts of the nerve trunk, is a procedure which is successful in preventing neuroma formation.

NERVE TRANSPLANTS

The great majority of the experimental observations listed in the following series deal with cases in which, owing to loss of nerve substance at the time of injury, the severed nerve ends were separated to such extents that they could not be brought together for suture. The question of bridging defects in nerve resulting from loss of substance at the time of injury is one that has received consideration for a time nearly coincident with that of the use of suture in uniting severed nerves. It is not proposed to enter on a general discussion of the methods used or suggested for the purpose of bridging nerve defects nor to consider critically the extensive literature bearing on this question; incidentally, certain pertinent references will be considered. Certain of the methods suggested as of service in bridging nerve defects which have received general recognition, such as suture à distance, tubular suture, nerve implantation and nerve flaps, were tested experimentally by Huber [30] several decades ago and discarded as not justified on experimental grounds. A few of these methods, such as the operation of nerve flap made from the central or distal stump, or from both stumps are still in use by surgeons. A critical review of all of the cases in which the operation of nerve flap was used to bridge a nerve defect was made by Stookey [50], who found that in not a single case was there conclusive evidence of regeneration. There has been a revival of the operation of nerve implantation, in case of loss of nerve substance in peripheral nerves, as a result of the advocacy of this method by Hofmeister [51], but there is no warrant for this method if properly done. It is only when nerve fibers are cut in the sound nerve at the seat of implantation, in which case the operation becomes one of nerve crossing, that there is any justification for attempting the method. Consideration is given to tubular suture in Series No. 20.

The use of a segment of nerve to bridge a defect due to loss of substance in a nerve has long been advocated, by both the experimenter and the clinician. This procedure was first tried experimentally by Philipeaux and Vulpian [66] and was first used by Albert [67] in human surgery. A segment of nerve used to bridge a defect in a peripheral nerve, taken from another nerve from the same individual, is designated an autogenous transplant or graft—an auto-nerve transplant; a segment of nerve taken from another individual but of the same species is known as a homogenous transplant or graft—a homo-nerve transplant; a nerve segment taken from another individual but of a different species is called a heterogenous transplant or graft—a hetero-nerve transplant. Having in mind the practical application in human surgery, various types of nerve transplants were tested experimentally, such as normal or degenerated nerves; fresh and preserved or stored in aseptic state; as single nerves or a bundle of nerves, the latter known as "cable-nerve transplant" or "multi-nerve transplant"; and wrapped or unwrapped in protecting membrane or sheath. These series constitute a very comprehensive experimental study of the question of nerve transplant.

SERIES NO. 5

AUTO-NERVE TRANSPLANTS, INCLUDING CABLE-AUTO-NERVE TRANSPLANTS

General surgical experience regarding the question of tissue graft or transplants, and the favor with which autogenous tissue grafts are regarded, made it imperative that auto-nerve transplants be given special consideration, even though it was recognized that in using an autogenous nerve transplant a normal functioning nerve was of necessity resected to the extent necessary to bridge the existing defect, with consequent loss of function in the nerve resected, throughout its entire field of distribution. Consideration should be given the fact that a nerve transplant should have a cross-section area approximately that of the nerve to be repaired, in order to admit of ready downgrowth of central neuraxes. The mere question of determining the relative value of an auto-nerve transplant as over against other types of nerve transplants did not appear to have sufficient value, since it could hardly be regarded as good surgery to resect one major nerve of an extremity to repair another even though an auto-nerve transplant should on experimentation prove to have special merit. In our endeavor to make auto-nerve transplants of practical use in surgery, the operation here known as cable-auto-nerve transplant was developed and tested experimentally. This operation consists in using several segments of a nerve which could be resected without serious inconvenience as a result of loss of function. Certain cutaneous nerves were selected for this purpose and a sufficient number of segments placed side by side so that their combined cross-section area approximated that of the nerve to be repaired. These operations were made with great care, especially those in which cable transplants were made. It is so essential to obtain good end-to-end approximation in nerve suture and it was our special endeavor to obtain this. In valuating these and other experiments in the light of possible application to human surgery, it is recognized that a direct transfer of results is not permissible. The aseptic wounds in normal tissue and the nerve resected by means of sharp instruments present a condition not found in a severed nerve torn or crushed by high explosive or otherwise, perhaps wound infected, and perhaps not seen until months after injury with abundant formation of scar tissue. It was felt, however, that certain general deductions could be made and certain general principles formulated. In suturing the nerve transplants very fine silk threads, waxed with sterile wax, were used. It is essential and necessary to have good approximation of the cut surface. This is more readily attained with waxed silk sutures passed through the nerve transplant and the resected ends of the nerve than when catgut is used. Stookey [68] and Elsberg [69] have described special technical methods, recommended for use in cable-auto-nerve transplants in human surgery. This operation is not an easy one and is very time consuming. It generally necessitates the making of a second wound, which even though it is quite superficial, is of necessity of some length. It is suggested that for purpose of cable-auto-nerve transplant the internal saphenous nerve, the anterior femoral cutaneous, and the sural nerve from the lower extremity and the cutaneous branch of the musculocutaneous (lateral antibrachial cutaneous)

and dorsal antibrachial cutaneous from the upper extremity are, of the larger cutaneous nerves, available.

The protocols of experiments under Series No. 5, auto-nerve transplants and cable-auto-nerve transplants follow:

PROTOCOLS

Experiment No. 64.—Dog No. 6; large; full grown; somewhat emaciated; 119 days. April 11, 1918, left sciatic exposed for a distance of 6 cm. Incision made through skin and muscle; free bleeding. Superficial radial of right forearm exposed and freed of connective tissue. Using No. 60 linen thread and fine, straight, round needles, two sutures passed through nerve about 3 cm. apart. Radial cut with scissors 2 mm. proximal and distal to suture lines and nerve segment transferred to sciatic wound. One needle and suture passed through sciatic centrally and sciatic cut 2 mm. distal to suture line; central suture tied. Distal suture passed through sciatic and the nerve cut 2 mm. proximal; distal suture tied. Only fair central and distal approximation of nerve ends attained. Radial segment has much smaller diameter than the sciatic nerve. Wounds closed. August 8, killed. Dog much emaciated, has not been well for several days. Left hind foot, small neurotrophic ulcer of heel; does not stand on ball of foot. Scar tissue found in line of sciatic wound; extends to deeper tissues. Left sciatic found surrounded by dense fibrous tissue. On dissecting free, a large central bulb noted. A small nerve bundle can be traced from this to distal sciatic stump. Distal sciatic presents the appearance of a partially regenerated nerve. Calf muscles exposed and sciatic and the transplant freed from the bed. On slowly cutting with scissors, sciatic central to the transplant, distinct twitching of calf muscles noted; same when sciatic is cut distal to the transplant. Sciatic and transplant and internal and external popliteal branches removed and fixed in ammoniated alcohol for pyridine-silver staining. After silver staining this material was by accident overheated in oven; section series unsatisfactory.

Microscopic findings.—In very broken and irregular sections, sufficient evidence of down-growth of neuraxes from the central bulb to warrant the conclusion that neuraxes coming from the central bulbous enlargement had grown through and outside of transplant to the distal sciatic stump. Details could not be determined.

Experiment No. 65.—Dog No. 7; large; full grown; well fed; 120 days. April 12, 1918, left superficial radial exposed and freed from connective tissue. Two silk sutures passed 2.8 cm. apart and nerve cut central and distal to sutured lines with sharp razor blade. Right sciatic exposed and freed. Radial segment transferred to sciatic wound and the sutures passed at the proper distance before the nerve was cut. Sciatic resected distal and proximal to suture line and sutures tied. Good approximation of nerve ends attained. Wound not quite dry; wounds closed. August 10, killed. Dog emaciated, but seems in good condition. Walks well; uses right hind foot quite normally; standing on ball of foot. On exposing the right sciatic a relatively large bulbous enlargement is found on the distal end of the central sciatic stump. A small bundle of nerves leads from this to the distal stump, the central end of which is not materially enlarged. Central sciatic bulb and the transplant not especially adherent to underlying muscle. Calf muscles exposed. After completely freeing the sciatic from notch to popliteal space, on slowly cutting the nerve central to the transplant distinct twitching and contraction of the calf muscles noted. Sciatic and transplant, external and internal popliteal and pieces of calf muscles and extensor leg muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—Large oval, central bulb evidenced structurally, from the distal end of which numerous down-growing neuraxes can be traced to the central end of the transplant and also into the connective tissue surrounding the central wound. In cross sections of the transplant its funicular structure is found retained, with the fibrous sheath thickened. Numerous neuraxes found in each of the funiculi of the transplant, also in small bundles in the connective tissue surrounding the transplant. In successive cross and longitudinal series of sections, these neuraxes can be traced to and through the distal wound into the distal sciatic branches; in the internal popliteal nearly to the level of the heel; in the external popliteal to the region of the head of the fibula. In sections of the calf muscles new neuraxes are found

in the larger and smaller muscular branches, and as single nerve fibers, between and on the muscle fibers. Here and there quite well developed motor nerve endings were noted.

Experiment No. 66.—Dog No. 3; small dog; full grown; 132 days. March 8, 1918, left sciatic cut, high up; wound closed. March 27, left sciatic exposed, nineteen days after section. Difficult to find central stump; much bleeding; muscles somewhat torn. Ends of cut sciatic stumps resected. Right ulnar exposed and a segment transplanted to the resected sciatic. Ulnar segment somewhat short; central suture gave way; difficult to suture again. One central and distal catgut suture used. Not good approximation attained; transplant ultimately 1.5 cm. in length. Wounds closed. August 6, killed. Dog in good condition; not materially emaciated. Uses left hind leg well; now and then steps on dorsum of foot; small ulcer on dorsum of foot. On exposing left sciatic large bulbous enlargement is found on central sciatic stump; from this a small bundle of nerves leads to distal sciatic stump. Distal sciatic, especially internal popliteal branch presents the appearance of a regenerated nerve. Central bulb and region of transplant surrounded by quite dense fibrous tissue; adherent to underlying muscle. After exposing calf muscles and freeing the sciatic from bed on slowly cutting sciatic central to transplant, feeble twitching of calf muscles noted. Muscle not fully recovered, pale red color, streaked with yellow white. Sciatic nerve and transplant, internal popliteal and portions of calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Fair differential silver staining attained.

Microscopic findings.—From the distal end of a long spindle-shaped bulbous enlargement, down-growing neuraxes may be traced through a long fibrous union, extending several millimeters, to the central end of the transplant. In cross sections of the transplant, about 1 cm. distal to the central wound, the funicular structure of the ulnar can only be partially made out; there is observed material increase of its fibrous sheaths. New neuraxes are observed within the funiculi of the transplant and also in the surrounding connective tissue, especially to one side. These new neuraxes can be traced in sections, to the distal wound and through it to the distal internal popliteal, the external popliteal not having been united to the transplant at the distal wound. In sections of the calf muscles, new neuraxes are noted in the muscular branches entering the several calf muscles, and in many of the interfascicular nerve branches.

Experiment No. 67.—Dog No. 8; large dog; full grown; 282 days. August 12, 1918, the left superficial radial exposed and freed from connective tissue. The right sciatic exposed by cutting through muscle; good direction of incision; free bleeding. Sutures passed through radial branch, 3 cm. apart before cutting the same, and transplanted to the resected right sciatic; good approximation attained. Muscle stitched over sciatic and transplant and the wounds closed. May 21, 1919, killed. Dog in good condition. Uses right foot well, though has slight limp in walking. On exposing right sciatic this is found embedded in loose connective tissue, interspersed with small fat globules. Large central bulbous enlargement noted, which extends in a fine nerve strand to the distal sciatic. In the region of the transplant diameter not quite half that of the sciatic. Calf and plantar muscles exposed. After freeing sciatic and the transplant from the bed, on slowly cutting the nerve with scissors, central to the transplant, distinct contraction of the calf and interossei muscles observed. On cutting the internal popliteal distal to the transplant the same observation noted. Sciatic transplant and the internal popliteal and several interossei muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—Long spindle-shaped central bulb evidenced structurally, from the distal end of which numerous neuraxes pass into the transplant and into the connective tissue surrounding it. In cross sections taken about 1.5 cm. distal to the central wound, it may be observed that the funicular structure of the transplant is still retained, surrounded by a distinct though not dense layer of fibrous tissue. Numerous new neuraxes are found within the surrounding connective tissue. In sections these new neuraxes may be traced to and through the distal wound into the distal popliteals. In the posterior tibial, both myelinated and nonmyelinated fibers may be traced to the level of the heel. In sections of several interossei muscles new neuraxes are to be observed in the muscular branches and here and there motor end organs are noted. Regeneration of distal popliteal to foot muscles, through the transplant.

Experiment No. 68.—Dog No. 2; medium size; full grown; 439 days. March 7, 1918, left sciatic exposed and cut high in thigh. March 26, 19 days later, severe neurotrophic changes left foot; foot in part missing. Left sciatic exposed; large central bulb noted. Central and distal sciatic stump resected. A segment of the right ulna of 2 cm. length transplanted. One central and distal No. 000 catgut suture used. Distal external popliteal resected for another operation; transplant sutured distally only to internal popliteal branch. Wounds closed. June 12, left foot completely healed; dog in good condition. May 20, 1919, killed. Dog in good condition; very active. Left foot to metacarpals missing. On exposing left sciatic this is found surrounded by loose connective tissue. Large bulb on central sciatic stump; this continuous distally with a nerve bundle about the size of ulnar traced to distal internal popliteal; external popliteal attached loosely to internal popliteal; no organic union. Calf muscle fully exposed; these have the appearance of normal muscle tissue. After completely freeing the sciatic from its bed, on slowly cutting the nerve with scissors central to the transplant, distinct contraction of the calf muscles observed. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good silver differentiation attained.

Microscopic findings.—Very large bulbous enlargement on central sciatic stump evidenced structurally, from the distal end of which numerous new neuraxes can be traced distally through a wide, central, fibrous wound, into the transplant and into the connective tissue surrounding the same. In cross sections of the transplant, about 1 cm. distal to the central wound, one large funiculus of the transplanted nerve segment clearly outlined by perineural sheath. Within this numerous myelinated and nonmyelinated nerve fibers, separated into small bundles by endoneural connective tissue, are observed. In the connective tissue surrounding the transplant numerous small bundles of nerves are found. These neuraxes can be traced through the distal wound into the distal internal popliteal, in which they are present in all of its funiculi, both as myelinated and nonmyelinated nerve fibers. Regeneration to lower level of popliteal space (the extent of nerve removed).

Experiment No. 69.—Dog No. 1; medium size; full grown; 81 days. May 16, 1918, right sciatic exposed and freed. Left ulnar exposed. Two segments of the left ulnar of approximately 3 cm. length transplanted to the resected right sciatic. Each ulnar segment sutured centrally and distally, separately to resected sciatic ends. Waxed, fine, silk thread sutures used; good approximation of the nerve ends attained. Wounds closed. August 5, killed. Dog in good condition; slight foot-drop right hind leg; very little neurotrophic change right hind foot. On exposing the right sciatic, transplants found well in place; no distinct central bulb. Transplant surrounded by loose connective tissue, not adherent to underlying muscle. Calf muscles exposed. After freeing transplant from bed on slowly cutting nerve central to the transplant, no contraction of calf muscles observed. Sciatic removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation only partially successful.

Microscopic findings.—In longitudinal sections through the central wound a central bulbous enlargement is clearly made out structurally, from the distal end of which numerous neuraxes traced into the transplant. In cross sections of the transplant the two ulnar segments clearly made out, each retaining its funicular structure. The two nerves are found surrounded by a common fibrous tissue sheath. Within the transplants new neuraxes found about equally distributed. The down-growing neuraxes can be traced into the distal wound and through this into the distal sciatic in which they may be traced in lessening numbers, approximately 3 cm. distal to the distal wound.

Experiment No. 70.—Dog No. 4; large dog; full grown; 152 days. March 8, 1918, left sciatic exposed and cut high in thigh. Wound closed. April 15, slight neurotrophic changes left heel; left sciatic again exposed, 38 days after section. Large neuroma on central sciatic stump; central end of distal sciatic only slightly enlarged. Central bulb removed and distal sciatic stump resected 5 mm. Two superficial radial branches, having parallel course, exposed and freed from connective tissue, brought together and clamped with artery forceps. Two No. 110 silk thread sutures formed 4 cm. apart and nerve cut with safety razor blade 2 mm. beyond sutures. The two nerve segments transferred to sciatic wound and sutured to resected sciatic ends; good approximation attained. Diameter of the two radial branches

not as great as the resected sciatic. Muscle stitched over nerve and transplant and wounds closed. April 23, superficial sciatic wound open to the extent 2.5 cm.; deeper wound seemed healed; no infection. August 7, killed. Dog very much emaciated; has not been feeding well for several days; left foot in part missing; nearly healed. Had had very severe neurotrophic changes of the foot. On exposing the left sciatic, contiguous muscles found to have yellow red color and much reduced in size. Large central sciatic bulb noted. A small nerve bundle extends from this to the distal sciatic stump. No material increase of fibrous tissue about the nerve. Calf muscles exposed; these appear very atrophic and not of normal color. After freeing nerve and slowly cutting the same central to the transplant no distinct contractions of calf muscles noted. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. In part good silver differentiation attained; not uniformly stained.

Microscopic findings.—Large central bulbous enlargement evidenced structurally, from the distal end of which numerous neuraxes can be traced to the central ends of the transplanted nerve segments and the connective tissue surrounding the same. In cross sections of the transplant, about 1.5 cm. distal to the central wound, both of the transplanted nerve segments clearly made out, with the funicular structure retained. The transplanted nerve segments surrounded by a common, fairly dense, fibrous sheath, which extends between the nerves. Within the funiculi of the transplant many new neuraxes observed; there appear to be more of these in one nerve than in the other, though this can not be definitely determined since the silver differentiation is not uniform. In the connective tissue surrounding the transplant many small bundles of nerve fibers encountered; this mainly to one side. New neuraxes in large numbers may be traced to and through the distal wound into the distal popliteal stump, for a distance of about 4 cm., the extent of the nerve removed for sections.

Experiment No. 71.—Dog No. 15; large, black hound; full grown; 376 days. May 8, 1918, superficial radial exposed and freed from connective tissue cut to segments about 4 cm. length, placed side by side and clamped at each end with artery forceps. Thus suspended, two fine, silk sutures passed through the two nerve segments 2.2 cm. apart, cut beyond suture lines and transplanted to the resected left sciatic, in suturing only the internal popliteal bundle used, external popliteal disregarded. Fairly good approximation of nerve ends attained. Wounds closed. May 20, 1919, killed. Dog in very good condition; still favors the left hind foot; no distinct foot or toe drop noted. Shape and size of bulb in part due to large bulbous end on external popliteal. From the distal end of the bulb there may be traced a nerve bundle to the internal popliteal. Calf muscles and foot muscles exposed. After freeing sciatic and the transplant from the bed, on slowly cutting with scissors central to the transplant, good contraction of calf muscles noted; foot muscles contraction feeble and uncertain. External popliteal cut, but not included in the sutures, is distally found closely united to internal popliteal. Cutting of external popliteal near head of fibula calls forth good contraction of leg flexors. Sciatic and transplant and two interossei muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—Very large bulbous end on central sciatic evidenced structurally. In longitudinal sections of this bulb. the unabsorbed central suture observed. Down-growing neuraxes, crisscrossing in every direction, reach the distal part of the bulb and can be traced to central ends of the transplants and the surrounding connective tissue. In cross sections of the transplant at two levels, near central and distal wounds, only one nerve bundle is clearly demarked. Whether there exists an error of record and only one nerve bundle was transplanted and not two as recorded, or whether one of the bundles pulled free centrally and disappeared, can not now be determined. The single nerve present is surrounded by a dense, felted layer of fibrous tissue. Within its funiculi numerous, both myelinated and nonmyelinated, neuraxes found; largely arranged in small bundles separated by endoneural connective tissue. In the connective tissue surrounding the transplant in centrally and distally placed cross sections, many small bundles of nerve fibers found. Neuraxes found within and without the transplant may be traced through the distal wound to the distal popliteal, in which in successive levels they are observed in cross and longitudinal sections to the level of the heel. In sections of interossei muscles new neuraxes are observed in the small interfascicular nerve branches and in one instance in a neuromuscular spindle. Com-

plete distal regeneration of the internal popliteal and branches, through the transplant, attained.

Experiment No. 72.—Dog No. 14; relatively large dog; full grown; 91 days. May 2, 1918, left sciatic exposed and freed. Two branches of the cutaneous radial exposed and freed from connective tissue. Two segments of the larger nerve of 2.5 cm. length transplanted to the resected internal popliteal branch of sciatic; one central and distal silk suture and one segment of the smaller nerve of 2.5 length transplanted to the resected external popliteal; one central and distal silk suture; good central and distal approximation attained in all three segments of cutaneous nerves used as transplants. Muscles stitched over nerve and transplant and wounds closed. May 14, severe neurotrophic changes left foot; possible infection of foot. Sciatic and forearm wounds healed. August 2, found dead in the morning; had not been eating well for several days; very much emaciated; still neurotrophic changes of foot. On exposing the left sciatic indistinct central bulb noted. Several bundles of nerves lead from this to the distal sciatic; can not determine definitely whether these nerve bundles are within the transplanted nerve segments. Distal sciatic does not present the appearance of normal nerve. Sciatic and internal popliteal removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation only partially successful.

Microscopic findings.—In longitudinal sections of the central wound, scarcely any evidence of central bulb noted on microscopic inspection, under the microscope crisscrossing of central neuraxes as they pass to transplant is noted. In cross sections of the transplant, the three transplanted nerve segments quite clearly made out; found surrounded by a common fibrous tissue sheath. Within the three transplanted nerve segments the funicular arrangement quite clearly retained. In each of these funiculi are found new neuraxes, quite evenly distributed. Very few neuraxes found in the connective tissue outside of the funiculi. The new neuraxes may be traced into the distal stump in which they are found in good numbers 3 cm. beyond the distal wound, the extent of the nerve sectioned.

Experiment No. 73.—Dog. No. 9; large; full grown; 323 days. June 29, 1918, right sciatic exposed and freed from bed. Two branches of the left cutaneous radial exposed and freed from connective tissue. Three segments of these nerves having a length of 2 cm. each sutured separately between the resected ends of the sciatic, using three No. 00 catgut sutures softened for a short time in sterile distilled water. Only fair approximation of the nerve ends attained. Dry field obtained by use of adrenalin. Wounds closed. May 18, 1919, killed. Dog in good condition; walks well; severe skin disease; nails on two inner toes long and curved so as to form complete circle. On exposing the right sciatic no material increase of connective tissue about the nerve noted; quite large central bulb, with transplant well in place. Calf muscles exposed; sciatic and transplant freed the entire length. On slowly cutting with scissors the nerve central to the transplant, good contraction of calf and flexor leg muscles noted. Foot muscles exposed, on cutting posterior tibial near heel, good contraction of the plantar interossei muscles observed. Sciatic, transplant, posterior tibial, pieces of calf and interossei muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation attained.

Microscopic findings.—In longitudinal sections of central wound region a large central bulb evidenced structurally from the distal end of which numerous neuraxes extend to the central end of the transplant. In cross section of the transplant at two levels, near central and distal wounds, only two of the transplanted nerves made out, both of these have retained their funicular structure. The fate of the third nerve segment can only be conjectured; it is thought that it pulled free centrally and completely degenerated. Within the funiculi of the two nerve segments present there are found numerous new neuraxes. In the more centrally placed cross sections numerous small nerve bundles are found in the connective tissue surrounding the transplant; scarcely any of the extra funicular nerve bundles are found in the cross sections of the lower level. New neuraxes were traced in the distal internal popliteal to the level of the heel, and in sections of the interossei muscles into the smaller interfascicular muscular branches; motor and sensory muscle nerve endings were observed in sections of the interossei muscles. Complete peripheral regeneration attained, so far as distribution of peripheral motor branches is concerned.

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Experiment No. 74.—Dog No. 12; large; full grown; 11 days. April 26, 1918, left sciatic exposed and freed. Two superficial cutaneous radial branches exposed and freed from connective tissue. Free venous oozing in the wound; after freeing nerves they were bathed in partly clotted blood for about fifteen minutes. Four segments were made of the cutaneous radial branches, placed side by side, and clamped together at the ends with artery forceps. A single silk thread suture passed centrally and distally through the four nerve segments 2.5

Fig. 221.—Cross section through the middle of a cable-auto-nerve transplant, Experiment No. 74, 11 days after operation; pyridine-silver preparation. Note the new epineural sheath, seemingly uniting the four separate nerve segments into one compact nerve with many funiculi. The funicular structure of each nerve segment is well maintained

cm. apart, and the nerve segments were cut beyond the sutures and the sutures tied, thus forming a complete bundle. This bundle of nerve was transferred to sciatic wound and fixed between the resected ends of the sciatic by suturing the same to the underlying muscles. The resected nerve ends and the bundle of four nerve segments were united by one central and distal epineural suture. Only fair approximation of nerve ends attained. Muscle stitched over nerve and transplant. Wound closed. Oozing in radial wound not fully

controlled. Closed. May 7, killed. Forearm wound open; superficial sciatic wound open to the extent of 3 cm.; deep wound healed. Left sciatic exposed; transplants found well in place; surrounded by newly forming connective tissue. A small amount of sanguineous exudate surrounds nerve and transplants. Sciatic and the transplants removed and fixed in ammoniated alcohol for pyridine-silver staining. Very good differential silver staining attained.

Microscopic findings.—In longitudinal sections of the central wound, taking in 1 cm. each of central end of transplant and distal end of proximal stump; early stages of the downgrowth of central neuraxes very beautifully shown; the ends of the down-growing central neuraxes have reached the fibrous wound, which the more advanced are in the act of penetrating. Many of the central neuraxes terminate in relatively large end-discs, others show division, others still early stages of spiral formation. As yet no new neuraxes can be traced to the central end of the transplant. In cross sections of the transplant the four

FIG. 222.—Cross section through the middle of a cable-auto-nerve transplant, Experiment No. 75, 26 days after the operation; pyridine-silver preparation. The funicular structure of the four segments of the nerve used is well maintained. Newly formed epineural tissue has united the nerve segments so as to form a single nerve trunk

segments of nerve transplanted can be clearly made out, with the funicular structure of each stained and perineural sheaths not thickened. The four nerves surrounded by a common connective tissue layer, forming a new epineural sheath common to the four nerves. In both cross and longitudinal sections of the transplant the neuraxes of the transplanted nerves appear fragmented into irregular segments, still staining differentially in silver. Sheath nuclei only here and there noted; not well stained in silver. Distal sciatic in early stages of degeneration.

EXPERIMENT NO. 75.—Dog No. 10; large dog; full grown; 26 days. April 24, 1918, the left sciatic exposed and freed. Two cutaneous radial branches exposed and freed from connective tissue. These nerves cut into four segments of a little over 4 cm. length, placed side by side in two groups and together clamped at the ends with artery forceps. Two fine silk thread sutures passed 2 cm. apart in each group of two nerves, and the nerves cut a little beyond the suture. These segments of the cutaneous radial, with sutures in place, were transferred to the sciatic wound, and each pair sutured separately to resected ends of

the sciatic. Good approximation of nerve ends attained. Muscle stitched over nerve and transplant; wound closed. May 20, dog died during the afternoon; nerve removed about two hours after death; left hind foot, severe neurotrophic changes, slightly infected; sciatic wound well healed; forearm wound partly opened. On exposing the left sciatic no evidence of infection is noted; transplant found well in place and firmly united to resected nerve ends. Quite distinct bulbous enlargement on central sciatic noted; central end of distal stump not materially enlarged. The four transplanted nerve segments surrounded by newly formed connective tissue so as to form one bundle. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Very good silver differentiation attained.

Microscopic findings.—In longitudinal sections through the central wound and about 1 cm. each of sciatic and transplants, the central bulbous enlargement is seen to include the central wound and central sutures. Numerous neuraxes coming from the central sciatic can be traced through the central wound, in which they are found to crisscross in all direc-

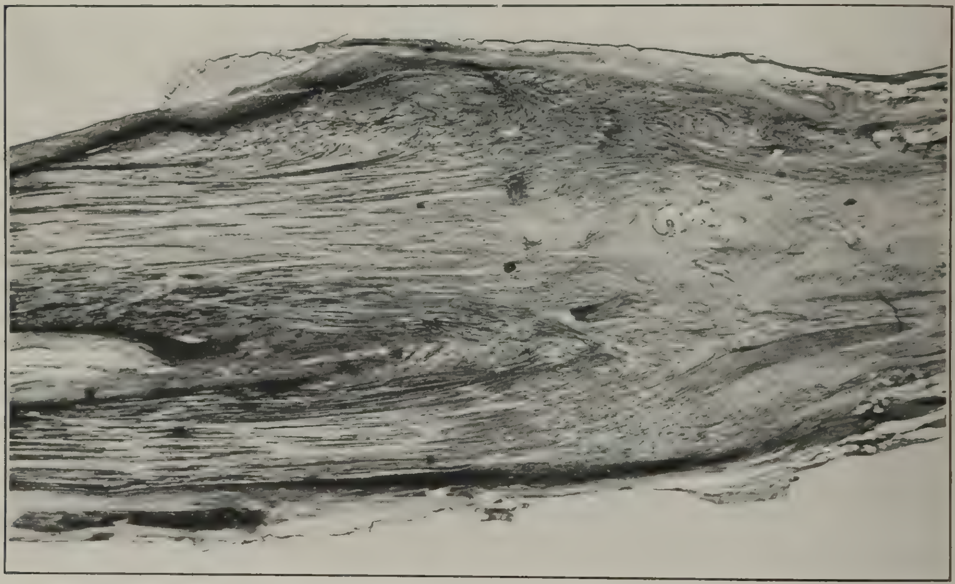

FIG. 223.—Longitudinal section through the central wound region, cable-auto-nerve transplant, Experiment No. 75, 26 days after operation; pyridine-silver preparation. The central end is found directed toward the left. The actual wound region found between the central and distal loops of the respective sutures is clearly seen in the figure

tions, into the central ends of the transplanted nerve segments. In cross section of the transplant, 1 cm. distal to the central wound, the four nerve segments transplanted can be clearly made out, each retaining its funicular structure, and are surrounded by a common fibrous tissue sheath serving as an epineural sheath, the whole transplant presenting the appearance of a relatively large nerve trunk with 10 larger and smaller funiculi; in about equal distribution there are found large numbers of new neuraxes, many found to be within old neurolemma sheaths, others in the endoneural tissue between these sheaths. Very few neuraxes observed in the connective tissue surrounding the several transplanted nerve segments. In longitudinal sections of the distal wound and adjacent nerve trunk it may be observed that certain of the down-growing neuraxes have reached the distal wound (transplant only 2 cm. in length), having thus nearly reached the central end of the distal sciatic. In this series of sections there was obtained very successful differential staining of neuraxes. Very often when this is the case the cellular elements of the tissue are not clearly stained; therefore this series of sections is not satisfactory for determining the behavior of the sheath cells of the transplanted nerve segments.

FIG. 224.—From a longitudinal section of the central wound region in cable-auto-nerve transplant, Experiment No. 75, 26 days after operation; pyridine-silver preparation. The figure illustrates clearly the course of the central neuraxes in passing through the scar tissue of the central wound. The funicular structure of the central stump is lost as the down-growing neuraxes pass through the wound

Experiment No. 76. —Dog No. 11; large dog; full grown; 109 days. April 25, 1918 left sciatic exposed and freed. The cutaneous radial branches exposed and freed from connective tissue. Quite a little venous oozing in the radial wound, so that the isolated cutaneous radial branches were bathed in partly clotted blood for 15 to 20 minutes. The cutaneous radial branches cut into segments of about 4 cm. lengths and placed side by side and together clamped at each end with an artery forceps. Two fine silk thread sutures passed 2.5 cm. apart, and nerves cut 2 mm. beyond the sutures. The sutures were then tied loosely and cut short, thus forming a compact nerve bundle of 2.5 cm. length, consisting of four segments of cutaneous radial. This bundle was transplanted to the resected left sciatic, and sutured centrally and distally by means of two fine silk thread epineural stitches. Fairly good approximation of cut nerve ends attained. Muscle stitched

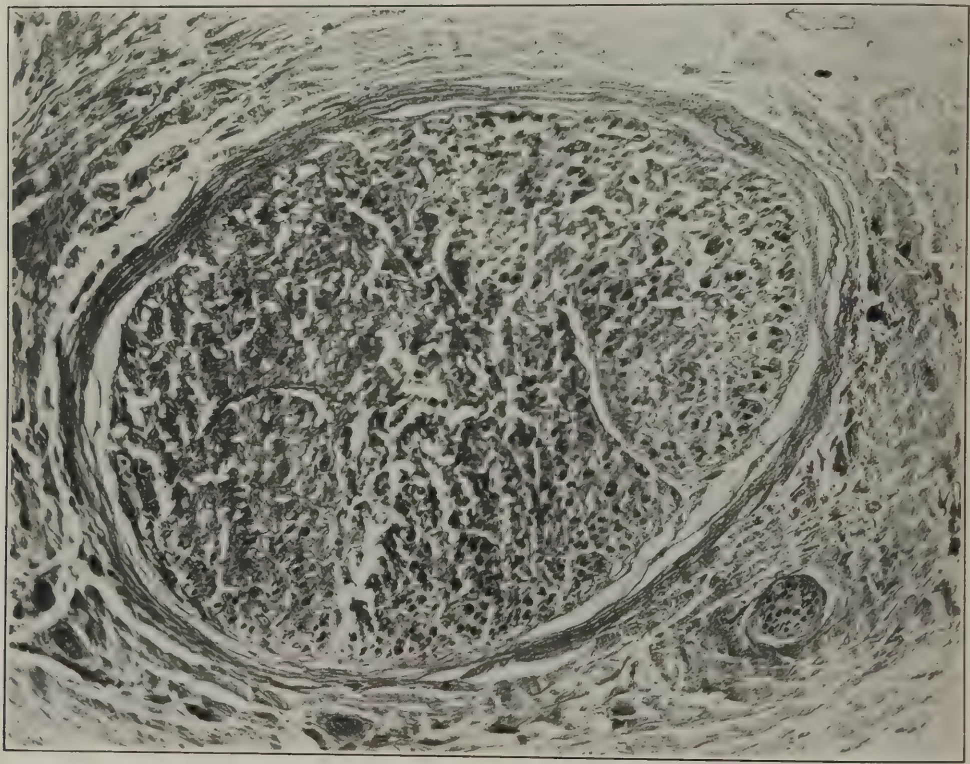

Fig. 225.—From a cross section of a cable-auto-nerve transplant, Experiment No. 75, 26 days after operation; pyridine-silver preparation. The figure presents a portion of one of the larger funiculi of a transplanted nerve segment as seen in Figure 222. The black dots represent cross sections of a single neuraxis or small bundles of such which grew through the central wound and into the neurolemma sheaths of the transplanted nerves

over nerve and transplant and wound closed. Forearm wound open a long time; not well protected; in part dry; bleeding not fully controlled. Wound closed. Both wounds healed well. August 12, killed. Slight foot- and toe-drop of left hind foot; walks quite well. On exposing the left sciatic no material increase of connective tissue about nerve and transplant is found. Quite distinct bulbous enlargement of the central sciatic is noted; slightly adherent to underlying muscle. From distal end of the central bulb several small nerve bundles can be traced to the distal sciatic stump, which presents the appearance of a regenerated nerve of nearly normal size. On exposing the calf muscles, these appear of nearly normal size and color and manifest quite rhythmic twitching. After freeing sciatic and transplant from bed, on slowly cutting sciatic with scissors, central to the transplant, distinct contractions of the calf muscles observed; the same on cutting distal to transplant. The sciatic

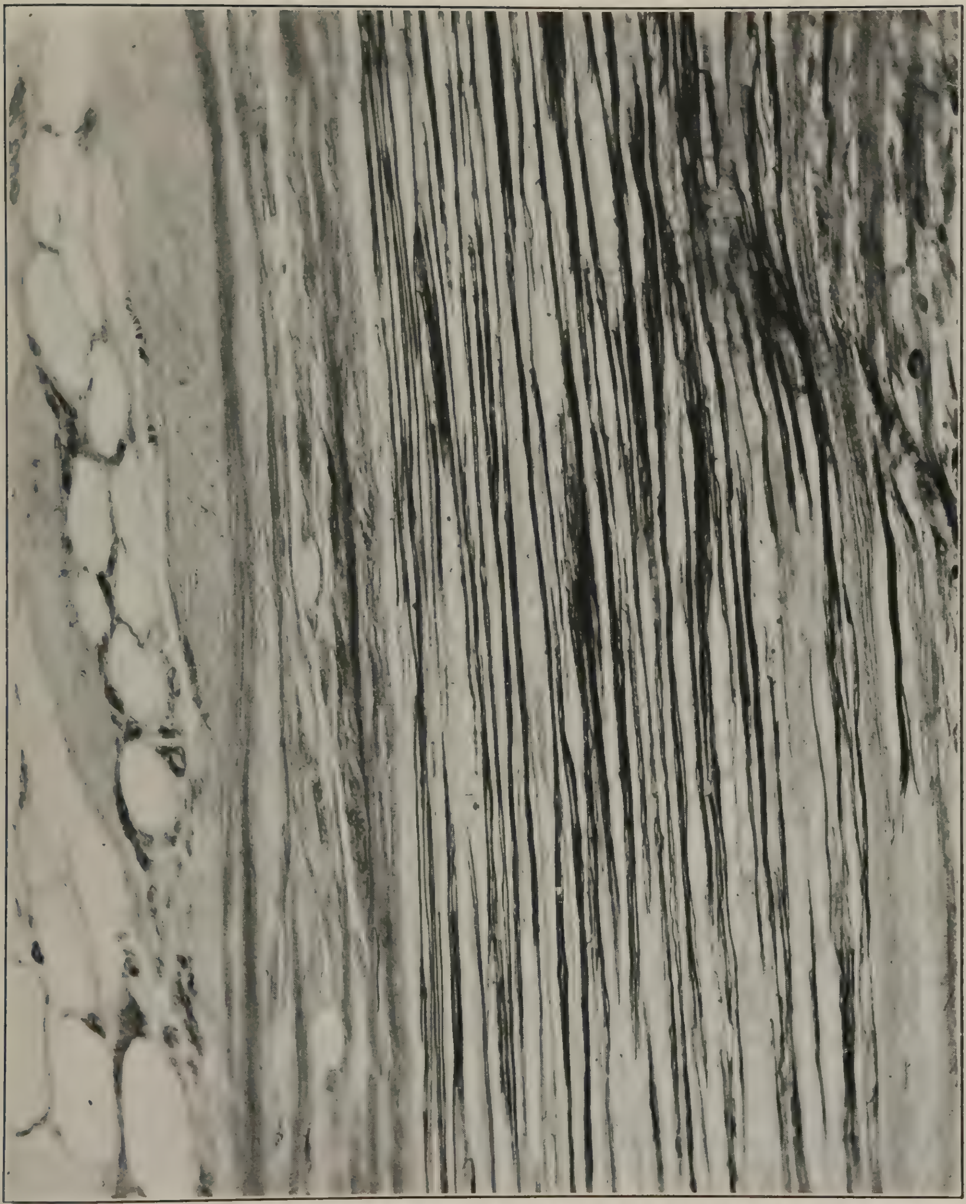

Fig. 226.—From a longitudinal section of the central third of a cable-auto-nerve transplant, Experiment No. 75, 26 days after operation. The figure presents a portion of one of the larger funiculi as seen in longitudinal section. Note the regular course of down-growing neuraxes, indicating that they are extending distally within the neurolemma sheaths of the transplanted nerves. (Compare with fig. 224)

and transplant, internal and external popliteal and posterior tibial, portions of calf and leg flexor muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. In part very good differential silver staining attained.

Microscopic findings.—In longitudinal sections of the central wound and adjacent nerve ends, central bulbous end is seen to include central wound and sutures and an area of small cell infiltration near one of the central sutures. Many new neuraxes can be traced from the central sciatic through the central wound into the central end of the transplant; others in the form of small nerve funiculi, having very tortuous course, are traced distally in the connective tissue outside of the transplant. In cross sections of the transplant, made about 1.5 cm. distal to the central wound, the four transplanted nerve segments with their respective funiculi can be clearly made out, and are found surrounded by a common fibrous tissue sheath, consisting of quite densely felted fibrous tissue. Numerous new neuraxes are found in each of the funiculi of the several transplanted nerve segments, also in the form of small nerve bundles in the connective tissue surrounding the nerve transplants. Neuraxes in large numbers can, in sections of successive levels, be traced through the transplanted nerve segments and distal wound into the distal sciatic stump. In cross sections of the internal popliteal at the lower level of the popliteal space, numerous new neuraxes are found in all of the several funiculi. In alternate cross and longitudinal sections of the distal internal popliteal, posterior tibial, and internal plantar new neuraxes were observed, these becoming progressively less numerous distalward, so that in the internal plantar only a few scattered neuraxes were found in an otherwise degenerated nerve. In sections of the calf muscles, numerous new neuraxes are found in the larger and smaller intramuscular nerve branches and as single nerve fibers on and between muscle fibers; here and there motor nerve endings are to be seen. Regeneration of the distal sciatic through a cable autonerve transplant attained. Partial regeneration of the distal nerve to the level of the internal plantar.

Experiment No. 77.—Dog No. 5; medium size; full grown; 152 days. March 8, 1918, left sciatic exposed and cut quite high in thigh; nerve ends retracted 8 mm. Wound closed. April 16, left sciatic exposed, 39 days after section. Dog in good condition; only slight limp noted. Large bulb found on the central sciatic stump, from which extends a fine nerve thread, which appears to reach the distal sciatic stump, which presents slight central enlargement; central and distal sciatic stumps resected; end 3 cm. apart. Two branches of the cutaneous radial exposed and freed of connective tissue, and cut in segments about 4.5 cm. long; placed side by side and clamped at each end with an artery forceps. Two No. 110 linen thread sutures passed through the four nerve segments 3 cm. apart. Nerves cut beyond suture lines and sutures tied loosely so as to form compact bundle. The same suture used to unite this nerve bundle to the ends of the resected sciatic; one extra epineural stitch central and distal; fairly good approximation of cut nerve ends attained. The four nerves together are only about two-thirds the diameter of the resected sciatic. Dry field; muscle stitched over nerve and transplant; wounds closed. Wounds healed well. August 7, killed. Dog emaciated; skin diseases; toe-drop on left hind foot; small ulcer on dorsum of foot. On exposing the left sciatic, there is noted an increase of connective tissue about nerve and transplant, especially in region of central and distal wound. No distinct central bulb observed and central end of distal sciatic only slightly enlarged. The four transplanted nerve segments surrounded by a common connective tissue sheath so as to form one nerve bundle about two-thirds as large as the distal sciatic. After exposing the calf muscles and freeing the sciatic and the transplant from its bed, on slowly cutting the sciatic with scissors, central to the transplant, indistinct, feeble twitching of calf muscles observed; this observed somewhat more clearly on cutting internal popliteal distal to the transplant. Calf muscles do not present normal color; pale red with narrow, light yellow streaks. Sciatic and the transplant with internal and external popliteal and portions of calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—In longitudinal sections of the central wound and the adjacent nerve ends, the central bulbous enlargment is found to embrace the central wound and central sutures. Numerous new neuraxes coming from the central stump can be traced through the central wound, in which they are seen to crisscross in all directions into the central ends of

the transplanted nerve segments. Many neuraxes are seen to pass distally in the connective tissue surrounding the transplanted nerve segments. In cross sections of the transplant, the four nerve segments transplanted are seen clearly demarked; each retaining its funicular structure. They are found surrounded by a common connective tissue sheath which serves as an epineural sheath. Numerous new neuraxes found in each of the funiculi of the four transplanted nerve segments. In the surrounding connective tissue, especially to one side, some 15 to 20 small nerve bundles are to be observed. New neuraxes can be traced in successive sections through the distal wound into the distal sciatic in which they are found in large numbers in all of the several funiculi. In sections of the calf muscles, new neuraxes are to be observed in the larger and smaller intramuscular nerve branches, and as single nerve fibers between and on the muscle fibers; a few motor nerve endings observed. Only partial regeneration of nerves in the calf muscles attained.

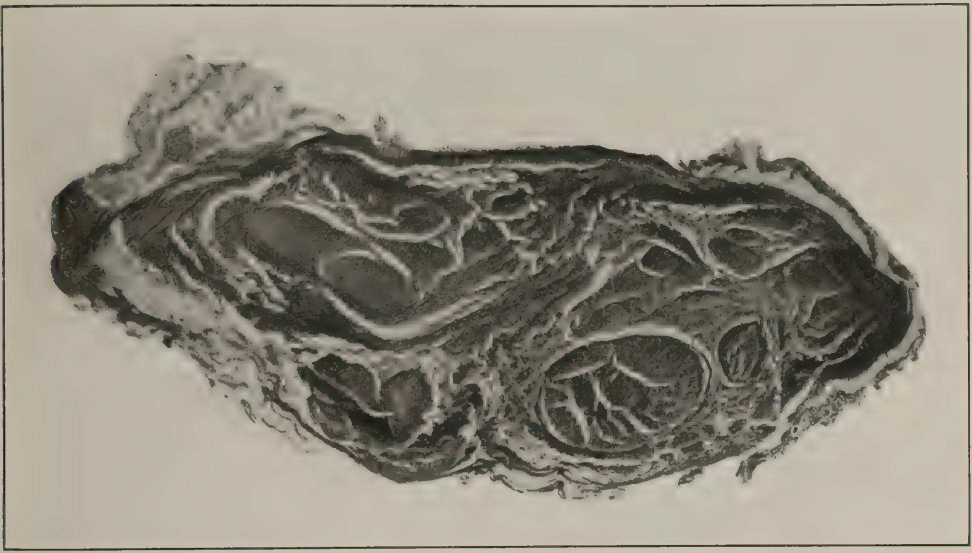

FIG. 227.—Cross section of cable-auto-nerve transplant, Experiment No. 77, 152 days after operation; pyridine-silver preparation. The four nerve segments used as a nerve bridge in this operation are clearly made out nearly four months after the operation

EXPERIMENT No. 78.—Dog No. 9; large dog; full grown; 389 days. April 24, 1918, left sciatic exposed and resected; quite free bleeding from the central stump; small artery ligatured. Two branches of the right superficial radial exposed and freed from connective tissue; cut into segments about 4 cm. long, placed side by side, and clamped at each end with an artery forceps. Two fine silk thread sutures passed through the four nerve segments 2 cm. apart and nerve cut beyond sutures. The sutures tied loosely, so as to form one compact bundle. This bundle transferred to sciatic wound and with one continuous suture each of the four nerve segments was sutured separately, centrally and distally, to the resected nerve ends; fine vessel silk was used for this suture. Muscle stitched over nerve and transplant; wounds closed. May 18, 1919, killed. Dog not in good condition, severe skin disease, active; walks well. Nails on two of the toes very long and curved. On exposing the left sciatic quite a large bulb found on the central sciatic; no distinct enlargement of central end of distal sciatic; transplant found well in place. Distal sciatic presents the appearance of a normal nerve. Calf muscles exposed; these have the appearance of normal muscle. After freeing sciatic from the bed, on slowly cutting nerve with scissors, central to transplant, calf muscles found to contract well, even though this functional test was made nearly forty minutes after the dog was killed. Contraction of the foot muscles not so clearly made out; they had not been exposed. Sciatic and transplant, distal popliteal and portions of interossei muscles removed, fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation attained.

Microscopic findings.—In longitudinal sections of the central wound and adjacent nerve ends, the central bulbous enlargement is found to include the central nerve wound and central sutures. Numerous neuraxes can be traced from the central sciatic through the central wound, in which they crisscross in all directions into the central end of the transplant. In cross sections of the transplant, though more than one year after operation, the four transplanted nerve segments can be clearly demarked, each with distinctive funicular structure. These four nerves are surrounded by a common fibrous tissue sheath which serves as an epineural sheath. Numerous neuraxes, many of which are myelinated, pass through the transplant to the distal sciatic; these are found about equally distributed through the several funiculi of the four transplanted nerve segments. Only very few neuraxes, in the form of several small nerve bundles, are found in the surrounding connective tissue. In longitudinal sections of the distal wound and adjacent nerve ends, there is also observed a crisscrossing of neuraxes; the neuraxes having here a very irregular course. In sections of the popliteal branches of the sciatic, to the level of the posterior tibial at the heel, new neuraxes in large numbers are to be observed. Unfortunately the pieces of interossei muscles removed at post mortem were lost in process of staining and can not be reported upon. In so far as miscroscopic evidence of nerves is concerned, nearly complete regeneration of distal branches of the sciatic was obtained.

Experiment No. 79.—Dog No. 13; large dog; full grown; 385 days. April 30, 1918, left sciatic exposed; resected. Two cutaneous radial branches exposed and freed from connective tissue. Each branch cut centrally and distally and pinned out, side by side, on piece of smooth wood, which had been sterilized with the instruments. With the nerves thus pinned out, sutures were passed so as to form two bundles of nerves, each with two nerve segments with sutures at each end; nerve bundles of 2.5 cm. length. Each of the two bundles, each composed of two nerve segments, was sutured separately between the resected nerve ends. One bundle was cut longer than the other, so that when they were sutured in place, one of the bundles presented a wavy course. Fairly good central and distal approximation of the nerve ends attained. Muscles stitched over nerve and the transplant; wounds closed. May 20, 1919, killed. Dog in very good condition; well fed and active; still seems to favor left hind leg a little; small ulcer on dorsum of the foot; two nails on this foot of large and irregular form. On exposing the left sciatic a distinct bulbous enlargement on central sciatic is found, from the distal end of which several nerve bundles are seen to pass to the distal sciatic stump. Distal sciatic and the popliteal branches present the appearance of normal nerves. Calf and leg flexor muscles fully exposed; after freeing sciatic and transplant from bed, on slowly cutting sciatic central to the transplant, vigorous contractions of the calf and leg flexor muscles observed. Cutting of the posterior tibial at heel does not call forth distinct contraction of the interossei muscles. Sciatic and the transplant, internal and external popliteal branches, portions of calf and interossei muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—In longitudinal sections of the central wound and the adjacent nerve ends, it is quite clearly to be made out that good approximation of the severed ends was not obtained at the time of operation. Down-growing neuraxes coming from the central stump, on reaching the central wound, present a felt-work arrangement, crisscrossing in all directions; many can be traced into the connective tissue surrounding the transplants. In cross sections of the transplant, about 1 cm. distal to the central wound, the field is made up of large numbers of small nerve funiculi separated by fibrous tissue and three quite distinct funiculi, surrounded by perineural sheath. The latter appear to be the only funiculi surviving out of about ten as found in other experiments in which four segments of the cutaneous radial nerves were transplanted. Numerous neuraxes may be traced through the distal wound into the distal sciatic, in which they are found in sections taken at successive levels to the posterior tibial at the level of the heel. In both cross and longitudinal sections, made of pieces taken from the interossei muscles, new neuraxes may be observed in the intramuscular nerve branches, and nerve endings in at least one neuromuscular spindle. No fully formed motor endings were observed; however, this may be due to imperfect silver differentiation. Regeneration of the distal popliteal to the level of the interossei muscles attained.

Experiment No. 80.—Rabbit No. 2a; large; full grown; 21 days. March 18, 1918, left and right sciatic exposed. A segment of the right sciatic having a length of 1.5 cm. transplanted to the resected left sciatic. One through-and-through Chinese silk suture placed centrally and distally; wounds closed. April 8, rabbit found dead in the morning. Wounds well healed. On exposing the left sciatic transplant is found well in place. Distinct bulb on distal end of central sciatic stump noted. Sciatic and the transplant removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin.

Microscopic findings.—In longitudinal sections taken from the transplanted nerve segment, numerous small round cells, found mostly in the looser connective tissue outside of the perineural sheath, observed. In the transplanted nerve fibers, the myelin is found in the form of irregular globules, separated by a granular detritus. Neuraxis remains not clearly made out. No distinct proliferation of sheath cells can be observed in such broken-down fibers. The picture is not that of a Wallerian degeneration. Strands of what appear to be syncytial protoplasmic bands, with short, rod-shaped nuclei, are noted. These bands resemble those found in a peripheral nerve trunk after section. Small bundles of such protoplasmic bands are separated by areas having neurolemma sheaths in which myelin remains are found.

In all of the experiments of auto-nerve transplants, kept for a time sufficiently long to admit of nerve regeneration, the results obtained were very satisfactory. In five of these experiments (No. 64 to No. 68), only one small nerve was used to bridge a defect in a resected sciatic, in three (No. 69 to No. 71), two segments of ulnar or superficial radial nerves were used to bridge such a defect, and in two experiments (No. 72 and No. 73) three pieces taken from the cutaneous radial were sutured between the resected ends. In all of the several experiments there was noted a nerve bulb on the distal end of the central sciatic stump, in general the more prominent the less adequately the nerve defect was bridged. On the whole there appeared to be little difference in the results attained in a primary operation in which the nerve transplant was sutured in place at the time of resection of the sciatic or in a secondary operation (No. 66 and No. 88) in which the sciatic was resected, the wound closed to be reopened some weeks later, and a nerve transplant made. A study of the protocols of the respective experiment will show that the central neuraxes were found to grow through the transplant, and to a variable extent in the connective tissue surrounding the nerve transplanted, to reach the distal segment of the resected nerve. It is not the purpose to discuss at this time the relative merits of the auto-nerve transplants. This will be undertaken after considering the observations considered in Series No. 6 and No. 7. A somewhat further consideration may here be given to the six experiments (No. 74 to No. 79) in which four segments of the radial cutaneous nerves were used to bridge a defect in sciatic nerves the result of resection. This operation we have designated a "cable-auto-nerve transplant" or a multiple nerve transplant. The radial cutaneous branches of the dog are relatively small nerves consisting of three or four major funiculi and presenting the form of a flattened oval in cross section. Four segments of these nerves arranged in parallel bundles were sutured singly or in pairs or as one bundle between the resected ends of the sciatic, by both central and distal sutures. In the dog killed 11 days after the operation (No. 74), before regeneration could have taken place, attention is called to the fact that on exposing the nerve, the four nerve segments transplanted were found united in one compact bundle, having the appearance of a single nerve trunk, by newly formed connective tissue. This

newly formed connective tissue forming an epineural sheath surrounding and enclosing the four segments of nerve transplanted, giving in cross section the appearance of a nerve trunk with many funiculi. A little study of the cross section reveals the fact that each of the four nerve segments has in reality maintained its own identity, each showing its respective funiculi surrounded by perineural sheaths. In this experiment there is distinct evidence of an active downgrowth of central neuraxes, which have reached the central wound region but have not as yet penetrated the transplants. In the experiment (No. 75), which terminated 26 days after the operation, the transplanted nerve segments were found united in one compact bundle by a newly formed epineural sheath. However, in each nerve segment there can easily be determined the several funiculi, each surrounded by a distinct perineural sheath. The transplanted nerve segments were found firmly united to the central and distal stumps of the resected nerve. The nerve segment removed for study included the distal end of the central stump to the extent of about 2 cm., the transplant, and some 3 cm. of the distal sciatic. This segment was divided into pieces so as to admit of longitudinal sections of the central and distal wound regions and contiguous transplant and sciatic segments and cross sections of the middle of the transplant. Nearly complete serial sections of the several pieces were made after the tissue had been stained by the pyridine-silver method. In the series of longitudinal sections of the central wound region, central neuraxes may be traced in large numbers through the central wound and into the central part of the nerve transplant. The picture presented is very much that of a section through the wound region after primary suture, except that in the cable auto-transplant the approximation of nerve ends is not so good; there is much more crisscrossing of the down-growing neuraxes. The cross-section series is very instructive. In the sections, taken from about the middle of the transplant, new neuraxes are found in all of the funiculi of the several transplanted nerve segments and in approximately equal distribution. Many of the neurolemma sheaths of the transplanted nerve fibers contain more than one neuraxis, others only one, and again others none. Very few neuraxes are found in the connective tissue outside of the funiculi. In the longitudinal sections, including the distal wound, it may be noted that the down-growing neuraxes in lessening number have penetrated the transplant to the region of the distal wound. The distal sciatic presents the picture of a degenerated nerve, the majority of the neurolemma sheaths containing syncytial strands.

In the remaining four of the cable auto-nerve transplants (No. 76 to No. 79) ranging in length of observation from nearly 4 months to a little over 12 months, even in those of long duration, could there be made out readily the four segments of nerve transplanted each with its several funiculi showing conclusively that the severed nerve segments formed definite paths along which the down-growing central neuraxes proceeded to reach the distal segment. In each of these four experiments was there a return of motor function as tested on the exposed muscles. This is corroborated by the presence of new motor endings in the calf muscles of certain experiments and even in the foot muscles of other experiments. The morphologic evidence of regeneration through several nerve segments as used in the operation of auto-nerve trans-

plants, it seems, is conclusive. It is here shown that it is possible to use several segments of a relatively small cutaneous nerve to bridge a defect in a major nerve, such as the sciatic, thus making available in human surgery the operation of auto-nerve transplant.

SERIES NO. 6

HOMO-NERVE TRANSPLANTS

Under Series No. 6 are presented observations on six experiments, all but one on the sciatic nerve of the rabbit, in which the sciatic was resected in one animal and a segment of requisite length removed from the sciatic of another animal used as a nerve bridge. The operation of homo-nerve transplant in human surgery has limited opportunity for application since it is to a large extent chance that would make available normal, fresh human nerve tissue to be used for purpose of transplant. As a secondary operation, where the operation of nerve repair may be timed, nerves from amputations may be made use of. We present an extended series of observations on the use of stored homo-nerve transplant which will be considered under a separate heading; in this series only operations in which fresh homo-nerve transplants were used are included.

PROTOCOLS

Experiment No. 81.—Rabbit No. 11a; full-grown rabbit; 8 days. March 14, 1918, right sciatic exposed and resected to the extent of 1 cm. A segment taken from the right sciatic of another rabbit, of 1.2 cm. length, used as a transplant. One central and distal Chinese silk suture placed. Fairly good approximation of nerve ends attained. Wounds closed. March 22, rabbit found dead in the morning. Sciatic wound healed. On exposing the sciatic, transplant found in place and united to the resected nerve ends. Sutures still show clearly. No distinct central bulb observed. Sciatic and transplant removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin.

Microscopic findings.—In series of longitudinal sections of the transplant, the myelin of the transplanted nerve fibers seen to be fragmented in many of the fibers. The neurokeratin net is clearly made out even in the fragments of myelin. Neurolemma sheaths very distinct. Sheath cells evident but do not manifest proliferation.

Experimemt No. 82.—Rabbit No. 1a; large rabbit; full grown; 8 days. March 18, 1918, the right sciatic exposed and resected 1.3 cm. The right sciatic of another rabbit exposed and a segment of 1.5 cm. length transplanted. One central and distal Chinese silk suture placed. Good approximation attained; a little clotted blood between nerve ends in distal wound. Wound closed. March 26, rabbit found dead in the morning. On exposing the right sciatic it is found that the central suture had given away a little; distal suture good. Sciatic and the transplant removed and fixed in neutral formalin for Bielschowsky silver staining.

Microscopic findings.—In a series of longitudinal sections of the transplant it is found that the epineural sheath has been invaded by numerous small round cells. In the transplanted nerve fibers the neuraxes are found to be fragmented; these fragments, differentially stained, are either bent upon themselves, are coiled, or have a wavy course. The myelin is not clearly defined; appears granular. The neurolemma sheaths intact and appear thickened. Sheath nuclei not differentiated.

Experiment No. 83.—Dog No. 36a; medium size; full grown; 17 days. June 4, 1918, right sciatic exposed and internal popliteal freed, and resected. A segment of 3 cm. length taken from the right internal popliteal of another dog, under the anesthetic at the same time, used as a transplant. One central and distal fine silk thread suture placed; very good approximation. The uncut external popliteal funiculus lies at the side of the operated internal pop-

liteal. Clean field; wound closed. June 21, dog found dead in the morning; very slight neurotrophic changes right hind foot. Wound well healed. On exposing the right sciatic the transplant is found well in place; appears as if slightly swollen; united to the resected nerve ends, though distally the wound had separated a little. No distinct central bulb noted. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Very good silver differentiation for the central segment attained.

Microscopic findings.—In longitudinal sections of the central wound and the adjacent nerve ends, central wound is clearly demarked by the presence of the central suture; good fibrous union. Only indistinct central bulb evidenced structurally. Numerous down-growing neuraxes of the central stump, end, often after branching, in large end-discs at the point of the fibrous union. Others have penetrated the fibrous tissue of this region and are found in the central end of the transplant in which they may be traced distally, becoming gradually less numerous, for a distance of nearly 1.5 cm. Now and again more than one neuraxis may be observed in old neurolemma sheath of the transplant. In cross section of the transplant about 1 cm. distal to the central wound relatively few neuraxes are to be found, scattered fairly evenly through the several funiculi of the transplanted nerve. In the distal popliteal stump early nerve degeneration stages observed. No new neuraxes traced to the distal nerve.

Experiment No. 84.—Rabbit No 62; full grown; 23 days. March 21, 1918, right sciatic exposed and resected 1.2 cm. Right sciatic of another rabbit exposed, while nerve was being exposed rabbit died under anesthetic; operation completed and nerve used in transplant. One central and one distal Chinese silk suture placed; fair approximation. Wound closed. April 13, killed. Caudal half of rabbit paralyzed; cause not determined. Sciatic wound well healed. On exposing nerve, transplant was found well in place; slightly adherent to muscle bed. Central and distal sutures clearly made out; no distinct central bulb. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Very good silver differentiation attained.

Microscopic findings.—In longitudinal sections through the central wound region and adjacent nerve ends, numerous down-growing neuraxes, crisscrossing through the fibrous wound, can be traced into the central end of the transplant. In cross sections of the transplant, about its middle, the funicular arrangement of the transplanted nerve segment is found well retained. The fibrous sheaths of the funiculi found thickened, within them and between the funiculi are found numerous small round cells. Within the funiculi numerous down-growing neuraxes are to be seen. In many instances four to six or eight new neuraxes found in one old neurolemma sheath. Certain of these down-growing neuraxes have reached the distal wound and can be traced to the distal sciatic in which they extend for a distance of about 1 cm.

Experiment No. 85.—Rabbit No. 8a; full grown; 68 days. March 16, 1918, right sciatic exposed and resected a little over 1 cm. A segment of equal length taken from the right sciatic of another rabbit used as transplant. One central and distal Chinese silk suture placed; good approximation. Wound closed. May 23, killed. Severe neurotrophic changes right foot; rabbit in good condition. On exposing the right sciatic, transplant is found well in place; sutures clearly seen. Small spindle-shaped central bulb. After exposing the calf muscles and freeing nerve from bed, no contraction of muscles observed on cutting nerve central to the transplant. Calf muscles appear atrophic and of yellow-red color. Sciatic and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation attained.

Microscopic findings.—In longitudinal sections of the central wound and the adjacent nerve ends, it may be observed that numerous neuraxes pass from the central stump through the central wound to the central end of the transplant. In cross sections of the transplant it is to be observed that its fibrous sheaths are materially thickened and that its funicular structure is not fully maintained. Numerous new neuraxes are observed both within the funiculi of the transplant and especially to one side in the surrounding connective tissue. In sections taken at successive levels, the down-growing neuraxes may be traced into and through the distal wound into the distal sciatic in which they are found in good number 2 cm. beyond the distal found; the extent of the sections.

Experiment No. 86.—Rabbit No. 27a; full grown; 83 days. March 15, 1918, right sciatic exposed and resected about 1 cm. A segment of equal length taken from the right sciatic of another rabbit and used as transplant. One central and distal Chinese silk suture placed. The muscle stitched over the nerve and transplant and the wound closed. June 6, killed. Wound well healed; rabbit in good condition. On exposing the right sciatic transplant was found well in place, with nerve sutures still evident. Small central bulb observed. Transplant of smaller diameter than resected nerve and slightly adherent to the underlying muscle. After freeing nerve from bed and exposing the calf muscles, on slowly cutting central sciatic no contraction of calf muscles noted. Sciatic and the transplant and the internal popliteal removed and fixed in ammoniated alcohol for pyridine silver staining. Fairly good silver differentiation attained.

Microscopic findings.—In longitudinal sections of the central wound, the central suture appears in the sections, clearly indicating the region of the central wound. Numerous down-growing neuraxes coming from the central stump penetrate the central end of the transplant. In cross sections of the transplant the funicular structure is clearly demarked. In the funiculi numerous new neuraxes, evenly distributed, are to be observed. Several groups of small nerve bundles are found in the connective tissue surrounding the transplant. In successive series of sections these neuraxes can be traced into the distal sciatic stump in which they are present in large numbers to the extent of the sections, 2 cm. beyond the distal wound.

The experiments in which fresh homo-nerve transplants were used, though relatively few in number and of relatively short duration, nevertheless show conclusively the feasibility of using fresh homo-nerve transplants to bridge a nerve defect. In the last three of the experiments listed (No. 84 to No. 86), ranging in duration from a little over one month to nearly three months, the down-growing central neuraxes were traceable through the transplant and a variable distance into the distal sciatic stump. As seen best in cross sections of the transplant, the down-growing neuraxes are found within the neurolemma sheath of the transplanted fibers, in the endoneural tissue between the nerve fibers and in the connective tissue surrounding the perineural sheaths of the funiculi of the transplant. In Experiment No. 83, in which the sciatic of a dog was operated upon and the experiment terminated at the end of approximately three weeks, the series of longitudinal sections of the central wound region presents a typical picture of regeneration from the central nerve stump with many branching central neuraxes and many down-growing neuraxes terminating at various levels in end-discs. These down-growing neuraxes are traceable through the wound region and into the central end of the transplant. No neuraxes are found in the distal wound region; the distal sciatic presenting a typical picture of a degenerated peripheral nerve of about three weeks standing.

SERIES NO. 7

HETERO-NERVE TRANSPLANTS

There can be no question that should hetero-nerve transplants prove to be a feasible operation it would become the operation of choice in cases in which a nerve bridge was found necessary. Therefore, it seemed to us worth while to reinvestigate the merits of a hetero-nerve transplant. In the majority of the experiments of this series (No. 87 to No. 125) one or two sciatic nerves, taken from the guinea pig, were used to bridge defects in the sciatic of rabbits, the result of resection. In a few experiments a nerve taken from a dog was used

to bridge a resected sciatic of a rabbit. The operated animals were killed at stated intervals, ranging in the several experiments from three days to nearly a year. Only fresh nerves were used for purposes of transplants. While one animal was under an anesthetic having one of the sciatic nerves exposed, resected, and sutures placed, a guinea pig (or dog) was placed under anesthesia, the region of the operation shaved and made aseptic, so that at the proper time the desired nerve could be exposed, a segment of requisite length taken and transferred to the host and sutured in place. In a number of instances two sciatics of a guinea pig were used to bring the diameter of the transplant to approximate that of the nerve to be bridged. Especial care was taken to suture the transplant to the resected nerve ends with as good end-to-end approximation as was possible so as to make the conditions favorable for regeneration.

PROTOCOLS.

Experiment No. 87.—Rabbit No. 73; old; large rabbit; 3 days. April 22, 1918, left sciatic exposed; resected about 1 cm. The two sciatics of a half-grown guinea pig exposed, exsected and placed side by side and clamped at ends with artery forceps. Two fine silk threads passed a little over 1 cm. apart through both nerves, and nerves cut beyond sutures. The two nerves together used as a transplant and sutured to the resected ends of the sciatic. Wound closed. April 25, killed. Superficial wound found healed; deep wound easily separated. On exposing the sciatic it was observed that one of the nerves used as a transplant had separated from the central stump; the other from the distal stump; the respective ends lying free in the wound. The sciatic and the transplanted nerves removed and fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation of central sciatic stump attained.

Microscopic findings.—In sections it is evident that the ends of the transplanted nerve segment were not well sutured to the resected ends. In longitudinal sections of the distal end of the central sciatic stump, many of the central neuraxes present distinctly swollen ends, many of irregular shape; no distinct fibrillar differentiation is made out. No clear evidence of the downgrowth of central neuraxes is observed. Transplanted nerve segments and the distal sciatic not clearly differentiated in this series.

Experiment No. 88.—Rabbit No. 73a; old; large rabbit; 3 days. April 22, 1918, right sciatic exposed and resected about 1 cm. Both of the sciatics of a half-grown guinea pig exsected and together used as transplant. One central and distal silk thread suture used. Wound closed. April 25, killed. Superficial wound found healed; deep wound easily separated. On exposing nerve, transplanted nerve segments found well in place. Sciatic and transplants removed and fixed in Flemming's chromo-osmic-acetic mixture. Sections stained in safranine and licht grün.

Microscopic findings.—In longitudinal sections of the central and distal wound regions, it is evident that there was good end-to-end approximation of the ends of the transplanted nerve segments and the resected sciatic. Central and distal wound region consists of a loose fibrocellular tissue. In cross section of the transplanted nerve segments, the funicular structure of the respective nerves well maintained. The two nerves found surrounded by a common layer of exudate with beginning fibrous tissue formation. Evidence of inwandering of leucocytes; these found between the nerve fibers. Very little fragmentation of the myelin of the transplanted nerve fibers observed; their sheath cells only indistinctly stained. In the distal sciatic beginning fragmentation of the myelin and the beginning of proliferation of the sheath cells noted; here and there a mitotic figure in these.

Experiment No. 89.—Rabbit No. 74; full grown; 5 days. April 22, 1918, the left sciatic exposed and resected 1.3 cm. The two sciatics of a half-grown guinea pig together used as a transplant. One central and distal silk suture placed. Wound closed. April 27, killed. Superficial wound healed; deeper wound not fully united. On exposing nerve, transplants found well in place, though only one of the nerves is clearly made out; not adher-

ent to the underlying muscle. Nerve and transplant surrounded by sanguineous exudate. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good silver differentiation in the central stump attained.

Microscopic findings.—In longitudinal sections of the central wound region, beginning stages of the down growth of central neuraxes noted. Certain of these have reached the central wound region. Not good alignment of central end of the transplants and distal end of sciatic found. Silver staining not satisfactory for detail study of transplant. Distal sciatic beginning degeneration of peripheral fibers made out.

Experiment No. 90.—Rabbit No. 74a; full grown; 3 days. April 22, 1918, the right sciatic exposed and resected 1.5 cm. The two sciatics of a half-grown guinea pig used as a transplant. One central and distal silk suture placed. On suturing distally one nerve was twisted over other; half spiral turn. Wound closed. April 25, killed. Superficial wound healed; deep wound not completely healed. On exposing sciatic it is found that the external popliteal bundle was not cut, the transplant found sutured to internal popliteal; transplants well in place, easily demarked by presence of sutures. Internal popliteal and the transplant removed and fixed in Flemming's chromo-osmic-acetic mixture. Sections stained in safranine and licht grün.

Microscopic findings.—In longitudinal sections of central and distal wound regions, it may be observed that the ends of the transplanted nerves are bent over hook-shaped; thus not found in alignment with the resected nerve ends. In longitudinal sections of the distal end of the central stump, for a distance of about 8 mm., fragmentation of myelin of central fibers and proliferation of the sheath cells noted. In cross sections of the transplant, the funicular structure of the two nerves is well maintained, with exudate and newly forming fibrous tissue inclosing the two nerves. The perineural sheaths of the funiculi not thickened. Beginning of inwandering of cells through the perineural sheaths observed. Only in a few of the larger funiculi, and in these in the more peripherally placed fibers, is fragmentation of the myelin noted. The great majority of the nerve fibers of the transplanted nerves show as yet no distinct fragmentation of the myelin and no proliferation of sheath cells. In the distal sciatic the peripheral nerve fibers show fragmentation of myelin and proliferation of sheath cells.

Experiment No. 91.—Rabbit No. 69; large; full grown; 9 days. April 18, 1918, left sciatic exposed and resected 1.2 cm. The two sciatics of a half-grown guinea pig together used as a transplant. One central and one distal suture placed; good approximation. Wound closed. April 27, killed. Superficial wound healed; deep wound healing. On exposing the left sciatic transplant found well in place, surrounded by exudate and newly forming connective tissue, which unites the two nerves in one bundle. The transplant appears congested, giving it a pink-red color. Sciatic and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation attained.

Microscopic findings.—In a series of longitudinal sections of the central wound region, numerous neuraxes growing from the neuraxes of the central sciatic can be traced to the central wound region, which they have invaded. Certain of the neuraxes are seen to branch others to terminate in end-discs; the beginning of spiral formation seems evident. Fine naked neuraxes found in the fibrocellular central wound. In the transplant, especially near the central wound, the neuraxes of the transplanted nerve, found in the form of long segments, having a regular course. Further distalward shorter neuraxis segments are found. Distal sciatic presents early stages of degeneration.

Experiment No. 92.—Rabbit No. 69a; large; full grown; 9 days. April 18, 1918, right sciatic exposed and resected 1.2 cm. The two sciatics of a half-grown guinea pig together used as a transplant. One central and distal silk suture placed; good approximation. Wound closed. April 27, killed. Superficial wound healed; deeper wound healing. On exposing the right sciatic the transplants found well in place and surrounded by newly forming connective tissue. Sciatic and the transplant removed and fixed in Flemming's chromo-osmic-acetic mixture. Sections stained in safranine and licht grün.

Microscopic findings.—Transplant found well united to the resected nerve ends. In cross sections of the transplant, through its middle region, the two nerves transplanted clearly made out, each showing typical funicular structure. The two nerves united by a

thick, common fibrous tissue sheath, in which are seen numerous small round cells; these also in large numbers between the two nerves. Wandering cells have invaded certain of the nerve funiculi. In certain of the funiculi the nerve fibers more peripherally placed show fragmentation of the myelin, not distinctly evident in the more centrally placed fibers. Not all of the funiculi react in the same way. Certain of the sheath nuclei of the transplanted nerve fibers are found to stain deeply; others more faintly. No proliferation of these cells is noted. In the distal end of the central sciatic stump and in the distal sciatic there is observed a distinct increase in the number of the sheath cell nuclei; here and there mitotic division is noted. Fragmentation of the myelin, which varies in degree in different nerve fibers, is observed in the distal sciatic.

Experiment No. 93.—Rabbit No. 67; large; full grown; 9 days. April 18, 1918, left sciatic exposed and resected 1.4 cm. The two sciatics of a nearly grown guinea pig used as transplants. One central and distal suture placed; centrally good approximation, distally "fair." Wound closed. April 27, killed. Wound healed. On exposing the left sciatic, transplants found well in place; surrounded by newly formed connective tissue and adherent to the underlying muscle. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. For central portion of nerve good silver differentiation attained.

Microscopic findings.—In longitudinal sections of the central wound region downgrowing neuraxes in relatively small number are found to have reached the central wound region; branching of these neuraxes is observed. In longitudinal sections of the transplanted nerves, the neuraxes of the nerve fibers are found fragmented into longer or shorter segments, staining differentially in the silver. A distinct layer of fibrous tissue surrounds the transplant; this tissue incloses many small cells. Distal sciatic shows early stages of nerve degeneration.

Experiment No. 94.—Rabbit No. 67a; large; full grown; 9 days. April 18, 1918, right sciatic exposed and resected 1.5 cm. The two sciatics of a nearly grown guinea pig used as transplant. One central and distal silk suture placed. Clean, dry wound. Wound closed. April 27, killed. Wound healed. On exposing the right sciatic, transplant found well in place; surrounded by exudate and newly formed fibrous tissue, not adherent to underlying muscle. A dead space nearly surrounds transplant; in this a small amount of sanguineous exudate. Sciatic and transplant removed and fixed in Flemming's chrom-osmic-acetic mixture. Sections stained in safranine and licht grün.

Microscopic findings.—In longitudinal sections of the central and distal wound regions, the ends of the transplants are found united to the resected nerve ends by means of fibrocellular tissue. The wound regions surrounded by numerous small cells; these have penetrated the distal end of the central sciatic stump for a distance of about 2 mm. In cross sections of the transplant the two nerves clearly demarked, with funicular structure well maintained. These nerves as seen in cross sections present an appearance which resembles closely that of normal nerves. At the periphery of the funiculi, beginning breaking down of the myelin is noted. Inwandered cells are found here and there between the nerve fibers; not to equal extent in all of the funiculi. The distal sciatic presents early stages of nerve degeneration, with great increase in the number of the sheath cells, and fragmentation of the myelin.

Experiment No. 95.—Rabbit No. 71; large; full grown: 15 days. April 19, 1918, left sciatic exposed and resected 1.4 cm. The two sciatics of a nearly grown guinea pig used as transplants. One central and distal No. 110 linen thread suture placed; only "fair" central and distal approximation of the nerve ends attained. Wound closed. May 4, killed. Rabbit not well; emaciated; wound well healed. On exposing the left sciatic, transplant found well in place; seems of smaller diameter than when used; not adherent to muscle. Distinct central sciatic bulb noted. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. For central portion of nerve fair silver differentiation attained.

Microscopic findings.—In longitudinal sections of the central wound region a distinct central bulb evidenced structurally, from the distal end of which a few down-growing central neuraxes have reached and penetrated the central wound region; numerous bulbous end-discs on such neuraxes noted. Within the transplant the old neuraxes found in short segments still showing the differential silver staining. The distal sciatic presents early stages of degeneration.

Experiment No. 96.—Rabbit No. 71a; large; full grown; 15 days. April 19, 1918, right sciatic exposed and resected 1.2 cm. The two sciatics of a half-grown guinea pig used as transplants. One central and distal No. 110 linen thread suture placed; good central approximation, "fair" distal. Wound closed. May 4, killed. Rabbit not well; emaciated; wound was healed. On exposing the right sciatic transplant is found well in place and of dull white color. The two nerves are held together by scant connective tissue. Well developed central bulb noted. Sciatic and transplant removed and fixed in Flemming's chrom-osmic-acetic mixture. Sections stained in safranine and licht grün.

Microscopic findings.—Transplant found well united to resected nerve ends; fibrous union In cross sections of the transplant, the two nerves transplanted are clearly demarked with funicular structure well retained. The two nerves found surrounded by common connective tissue sheath infiltrated with small round cells; found in large numbers between the two nerves. Here and there cells which have penetrated the perineural sheaths are found between the nerve fibers. It may be observed that the peripheral fibers of the funiculi have their myelin and neuraxes more fragmented than those more centrally placed. Wandering cells found within certain of the neurolemma sheaths. In the distal sciatic the nerve fibers found in early stages of degeneration.

Experiment No. 97.—Rabbit No. 88; large; full grown; 42 days. August 20, 1918, the left sciatic exposed; internal popliteal bundle freed; resected 2.8 cm. A segment of equal length taken from the left sciatic of a full-grown guinea pig used as transplant. One central and distal suture of waxed fine silk thread used; good approximation. Wound closed. October 1, rabbit found dead in the morning; neurotrophic ulcer left heel. On exposing the left sciatic, it was found that the transplant remained united to the central sciatic stump, the suture showing, but had pulled free from the distal stump; its end lying free in the wound; the portion of the transplant remaining having a yellow-white color. Large bulbous end on central sciatic stump noted. Central sciatic and remains of transplant removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In cross sections of the remains of the transplant the funicular structure of the nerve found well maintained; the perineural sheaths invaded by small round cells. Within the perineural sheaths, large and in fact multinucleated masses of protoplasm, indefinitely bounded, are to be seen. In the nerve fibers, the neurolemma sheaths found containing globular masses, varying in size. This more particularly in the perineural fibers of the funiculi. The more centrally placed fibers found better preserved; certain ones still showing the neurokeratin net of the myelin.

Experiment No. 98.—Rabbit No. 88a; large; full grown; 33 days. August 29, 1918, right sciatic exposed; internal popliteal freed; resected 2.4 cm. The right sciatic of a full-grown guinea pig used as transplant. One central and distal waxed, fine silk-thread suture placed; good approximation. Wound closed. October 1, rabbit found dead in the morning; neurotrophic ulcer on right heel. On exposing the right sciatic, transplant was found well in place; no material increase of connective tissue. Transplant is of dull white color. No distinct bulb on the central sciatic stump noted. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. For central part of nerve good silver differentiation attained; for distal nerve not so good.

Microscopic findings.—In longitudinal sections of the central wound region a long spindle-shaped bulb evidenced structurally, including the central end of the transplanted nerve segment. Down-growing neuraxes coming from the central nerve are found to enter several of the funiculi of the transplant in which they can be traced several millimeters. In cross sections of the transplant taken about 1 cm. distal to the central wound, the funicular structure of the transplanted nerve is found well preserved, with the fibrous sheaths of the funiculi thickened. The old neuraxes of the transplanted nerve fibers evident within many of the neurolemma sheaths. No new neuraxes made out at this level. In longitudinal sections of the transplant, nearly all of the myelinated nerve fibers show remains of the neuraxes, as short segments of spiral form or looped, showing the characteristic silver reaction. The nerves of the distal popliteal found degenerated.

Experiment No. 99.—Rabbit No. 70; full grown; 34 days. April 19, 1918, left sciatic exposed and resected 1.2 cm. The two sciatics of a half-grown guinea pig used as transplants. One central and distal silk thread suture placed. Good central approximation attained; distal not good; an additional epineural stitch improves somewhat. Wound closed. May 23, killed. Wound well healed; beginning neurotrophic ulcer on the left heel. On exposing the left sciatic, transplant is found well in place, surrounded by fibrous tissue and found adherent to underlying muscle. Sciatic and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Very good differential silver staining attained.

Microscopic findings.—A large distinct central bulb evidenced structurally, from the distal end of which numerous neuraxes can be traced distally. Certain of the neuraxes can be traced into the central end of the transplanted nerves; others pass to the connective tissue surrounding the transplanted nerves or found between them. In cross sections of the middle of the transplant the two nerves are clearly made out. The two nerves are found surrounded by a common fibrous tissue sheath. At this level no new or down-growing neuraxes made out within the perineural sheaths of the nerve funiculi. In many of the nerve fibers fragments of the old neuraxes may be seen. In the fibrous tissue surrounding the transplanted nerves, mainly to one side, there are to be found numerous neuraxes, singly or in small bundles, separated by fibrous tissue. In longitudinal sections of the distal wound region it is evident certain of the down-growing neuraxes have reached this region and may here be traced into the central end of the distal popliteal. These new neuraxes appear to reach this level mainly by way of the connective tissue found surrounding the transplant.

Experiment No. 100.—Rabbit No. 70a; full grown; 34 days. April 19, 1918, right sciatic exposed and resected 1.4 cm. The two sciatics of a half-grown guinea pig used as a transplant. One central and distal silk suture placed. After suture, the two nerve segments transplanted found twisted one spiral turn; the central and distal approximation "fair." Wound closed. May 23, killed. Wound appeared well healed. On removing skin over wound area, a small focus of suppuration found in wound line; does not appear to extend to deeper wound. On exposing sciatic, tissue about nerve presents no evidence of infection. The transplant found well in place, surrounded by connective tissue and adherent to underlying muscle. No distinct bulbous enlargement of central sciatic noted. Sciatic and transplant removed and fixed in Flemming's chrom-osmic-acetic mixture. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In longitudinal sections including the central and distal wounds, the transplant appears well united to resected nerve ends; fibrous tissue union. An indistinct central bulbous enlargement is found, from the distal end of which down-growing neuraxes in the form of nonmyelinated nerve fibers may be observed; these approach the central ends of the transplanted nerve segments. In cross sections of the transplant, the funicular arrangement of the transplanted nerves found well retained; surrounded by a common fibrous sheath, showing much round cell infiltration. The nerve fibers of the transplant appear to be appreciably enlarged, with neurolemma sheath distinct. Within these sheaths here and there globular remains of myelin. Phagocytic cells found within the neurolemma sheaths. The nerve fibers of the distal popliteal found degenerated.

Experiment No. 101.—Rabbit No. 66; full grown; 50 days. April 17, 1918, left sciatic exposed and resected 1.3 cm. The two sciatics of a half-grown guinea pig used as a transplant. One central and distal No. 110 linen-thread suture placed. Fairly good approximation attained. Wound closed. June 6, killed. Rabbit good condition; no distinct neurotrophic changes of left hind foot. On exposing the left sciatic, transplants found well in place; surrounded by a common fibrous sheath; adherent to underlying muscle. A distinct bulbous enlargement on the central sciatic stump noted. Calf muscles fully exposed; these appear degenerated. On cutting nerve central to transplant, no contraction of calf muscles noted. Nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Very good differential silver staining attained.

Microscopic findings.—In longitudinal sections of the central wound region, a long spindle-shaped central bulb is recognized; line of union with central end of transplants clearly recognized by presence in the sections of central sutures. Numerous down-growing central neuraxes can be traced to the central end of the transplant, within which they are traced distalward for

a distance of nearly 1 cm. Certain of these neuraxes are found in the remains of the old neurolemma sheaths, found in the detritus derived from the transplanted nerve fibers. In cross sections of the transplant, taken about 1 cm. distal to the central wound, new neuraxes are to be observed within several of the funiculi of the transplanted nerve segments, even in the most necrotic portions. In longitudinal sections of the distal wound region, a few of the down-growing neuraxes can be traced from the distal end of the transplant into the distal wound and from this a few scattered neuraxes to the central end of the distal internal popliteal.

Experiment No. 102.—Rabbit No. 66a; full grown; 50 days. April 17, 1918, right sciatic exposed and resected 1.5 cm. The two sciatics of a half-grown guinea pig used as transplants. One central and distal No. 110 linen-thread suture placed; fairly good approximation. Wound closed. June 6, killed. Rabbit in good condition; scarcely any neurotrophic changes in right hind foot. On exposing the right sciatic, transplant found well in place; surrounded by connective tissue; only moderately adherent to the underlying muscle. Relatively dense fibrous tissue surrounds distal wound. Distinct bulbous enlargement noted on central sciatic stump. Calf muscles exposed; these have the appearance of degenerated muscle; do not contract on cutting nerve central to the transplant. Sciatic and transplant removed and fixed in Flemming's chromo-osmic-acetic mixture. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In longitudinal sections of the central wound region a very large central bulb is evidenced structurally, from the distal end of which numerous young nerve fibers, the majority of which are as yet nonmyelinated, are found to extend to the central end of the transplant, in which larger and smaller syncytial masses, irregular multinucleated giant cells, occupy the regions of the transplanted nerve fibers. In cross sections of the transplant the two nerve segments are recognized by their funicular arrangement and are surrounded by a common connective-tissue sheath. Within the perineural sheaths of the several funiculi, masses of large vesicular cells and irregular masses of syncytial protoplasm and granular detritus occupy the greater part of the cross-section area of each funiculus. In the fibrous tissue surrounding the transplanted nerve segments, especially to one side, there is observed an area in which some fifteen small funiculi of nerve fibers are to be found. No new nerve fibers were traced to the distal sciatic. The nerves of the distal sciatic found degenerated.

Experiment No. 103.—Rabbit No. 68; large; full grown; 61 days. April 18, 1918, left sciatic exposed and resected 1.4 cm. The two sciatics of a nearly-grown guinea pig used as transplants. One central and distal No. 110 linen-thread suture placed; good approximation. Wound closed. June 18, rabbit found dead in the morning; severe neurotrophic changes left hind foot. On exposing the left sciatic a large bulbous enlargement on the central sciatic stump is noted, from the distal end of which a fine strand, not quite the size of one of the sciatics used as transplant, leads to the distal sciatic stump. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Only in part good silver differentiation attained.

Microscopic findings.—In longitudinal sections of the central wound region a large spindle-shaped bulbous enlargement of end of central sciatic is evidenced structurally, from the distal end of which down-growing neuraxes may be traced to the central end of the transplant and the connective tissue surrounding the transplant. In cross sections distant about 1 cm. from central wound, the funicular structure of one of the transplanted nerves can be made out, with epineural sheaths thickened. Within the fibrous sheath areas of granular detritus and faintly outlined vesicular cells are noted. This mass occupies nearly the entire cross area of each funiculus. No down-growing neuraxes recognized in this detritus nor at this level in the surrounding fibrous tissue. The distal popliteal found completely degenerated.

Experiment No. 104.—Rabbit No. 68a; large; full grown; 61 days. April 18, 1918, right sciatic exposed and resected 1.5 cm. The two sciatics of a nearly-grown guinea pig used as transplants. One central and distal No. 110 linen-thread suture placed; good approximation. Wound closed. June 18, rabbit found dead in the morning; very severe neurotrophic changes right heel. On exposing the right sciatic, transplant found well in place; the two nerves distinctly evident; of dull white color. No distinct central sciatic bulb

noted. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Not well differentiated; not well embedded; sections torn.

Microscopic findings.—From well-developed central bulbous enlargement down-growing neuraxes can be traced in part into the central end of the transplant, the majority to the side of the transplant into the surrounding connective tissue. The remainder of the series of sections, especially those of the transplant, so badly torn, owing to faulty embedding, the resulting sections could not be used for critical study. The nerves of the distal sciatic stump found completely degenerated.

Experiment No. 105.—Rabbit No. 96; full grown; 69 days. September 6, 1918, left sciatic exposed and the internal popliteal freed and resected 2.5 cm. A segment of equal length taken from the left sciatic of a large guinea pig used as transplant. One central and distal waxed fine silk-thread suture placed; good approximation. Slight hemorrhage from central sciatic stump, not fully controlled. Wound closed. November 15, rabbit found dead in the morning; not well for several days; slight neurotrophic changes left heel. On exposing the left sciatic, the external popliteal found in close approximation to operated internal popliteal. Transplant found well in place and easily recognized by reason of its yellow-white color. Small spindle-shaped bulbous end central internal popliteal. Internal popliteal and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Only in part good silver staining attained; sections torn.

Microscopic findings.—In longitudinal sections of the central wound region certain downgrowing neuraxes are found to enter the central end of the transplant; the majority are seen to pass to the side of the transplant into the surrounding connective tissue. In cross sections of the transplant it is seen that the funicular structure of the transplanted nerve is well retained, with epineural sheath thickened. In many of the old nerve fibers of the transplant remnants of the old neuraxes seen, both in cross and longitudinal sections. The neurolemma sheaths seem thickened and contain granular detritus. No new neuraxes traced to the distal wound. The nerves of the distal popliteal found degenerated.

Experiment No. 106.—Rabbit No. 96a; full grown; 69 days. September 6, 1918, right sciatic exposed, internal popliteal freed; resected 2.5 cm. A segment of equal length taken from the right sciatic of a large full-grown guinea pig used as transplant. One central and distal waxed fine silk-thread suture placed; good approximation. Wound closed. November 15, rabbit found dead in the morning; not well for several days; severe neurotrophic changes right heel. On exposing the right sciatic, the central internal popliteal is found to end in a large bulb to which the central end of the transplant is adherent. The transplant had pulled free from the distal popliteal; the distal suture is found in the free distal end of the transplant. Central and distal internal popliteal and the transplant removed and fixed in neutral formalin. The sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht-grün.

Microscopic findings.—In longitudinal sections of the central wound region, active downgrowth of small myelinated and nonmyelinated neuraxes pass to the side of the transplant and are lost in the surrounding connective tissue. In cross sections of the transplant, just distal to central wound, it is observed that the funicular structure of the nerve is well retained; with each funiculus surrounded by a perineural sheath. The nerve fibers within the perineural sheaths of larger diameter; remnants of neuraxes noted. Under low magnification the cross sections of the transplanted nerve resemble closely in general structure a normal nerve. The nerve fibers of the distal popliteal completely degenerated.

Experiment No. 107.—Rabbit No. 89; full grown; 87 days. August 30, 1918, left sciatic exposed; internal popliteal freed; resected 3 cm. A segment of equal length, taken from the left sciatic of a large, full-grown guinea pig, used as a transplant. One central and distal waxed, fine silk thread suture placed; good approximation. Wound closed. November 26, rabbit found dead in the morning; much emaciated, on left heel neurotrophic ulcer. On exposing the left sciatic the transplant is found well in place, demarked by its light yellow color; no material increase of connective tissue about it. Distinct bulbous enlargement on central internal popliteal. Internal popliteal removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In longitudinal sections of the central wound region, from the large central bulb, there may be traced many small myelinated and nonmyelinated nerve

fibers to the central end of the nerve transplant. In cross and longitudinal sections of the transplanted nerve segment, it may be observed that the perineural sheath of the nerve is not materially thickened. Within this sheath large areas in which are found closely arranged large vesicular cells, with globular and granular inclusions, not clearly defined. Other areas in which similar cells and granular detritus are found in what appear to be distended neurolemma sheaths. Within the perineural sheath, mainly to one side, many small funiculi of nerve fibers may be observed. No new nerve fibers traced to and through the distal wound. The nerve fibers of the distal popliteal stump found completely degenerated.

Experiment No. 108.—Rabbit No. 89a; full grown; 87 days. August 30, 1918, right sciatic exposed; internal popliteal freed and resected 3 cm. A segment of equal length, taken from the right sciatic of a large, full-grown guinea pig, used as transplant. One central and distal waxed, fine silk thread suture placed; good approximation. Wound closed. November 26, rabbit found dead in the morning; much emaciated; severe neurotrophic ulcer right heel. On exposing the right sciatic, transplant is found well in place; no material increase of connective tissue and only moderately adherent to underlying muscle. Distinct central bulbous enlargement found. Internal popliteal and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation attained.

Microscopic findings.—In longitudinal sections of the central wound region, and series of sections at successive levels, the transplant is clearly demarked by reason of its jet-black staining. Down-growing central neuraxes can be seen to penetrate the central end of the transplant, in which they can be traced distally until the jet black, nontransparent coloration is reached; here they are lost to view. Certain of the central neuraxes pass to the side of the transplant, coursing distalward in the surrounding connective tissue. In cross sections of the transplant, the perineural sheaths are not found materially thickened. Within the sheaths the remains of the transplanted nerves so deeply stained—jet black—that no structural details can be determined, and it can not be ascertained whether central neuraxes have reached this level. In longitudinal sections of the distal wound region, a few neuraxes can be traced from the distal end of the transplant to the distal wound; others appear to reach the wound region from the surrounding connective tissue. Certain few neuraxes have reached the central end of the distal popliteal in which they have grown for a distance approximating 1 cm.

Experiment No. 109.—Rabbit No. 93; full grown; 96 days. September 4, 1918, left sciatic exposed; internal popliteal bundle freed; resected 2.5 cm. A segment of equal length, taken from the left sciatic of a full-grown guinea pig, used as a transplant. One central and distal waxed, fine silk thread suture placed; good approximation. Wound closed. December 10, killed. Rabbit moribund; breathing when killed; much emaciated, severe neurotrophic ulcer left heel. On exposing the left sciatic, the external popliteal is found closely adherent to operated internal popliteal; dissected free without cutting perineural sheath. Large spindle-shaped bulb on internal popliteal noted. The transplant is found well in place, but of small size; only about one-half the size as when used. Transplant presents several short stretches of yellow-white color. Calf muscles exposed; these are atrophic and of yellow-red color and do not contract nor show twitching on cutting nerve. Internal popliteal and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Fair silver differentiation attained.

Microscopic findings.—In longitudinal sections of the central wound region, a distinct central bulbous enlargement is evidenced structurally, this included the central end of the transplant, recognized as a granular mass of detritus and faintly stained vesicular cells. Central neuraxes may be traced mainly to the side of this mass into the connective tissue surrounding the transplant. In cross sections of the transplant, about its mid region, a very material thickening of its fibrous sheath is noted. Within this fibrous sheath there are found numerous small bundles of neuraxes, separated by bands of fibrous tissue. The necrotic remains of the transplanted nerve found to one side. In longitudinal sections of the distal wound region, certain neuraxes coming from the distal end of the transplant, more numerous from the connective tissue surrounding the transplant, can be traced through the distal wound into the distal popliteal nerve, in which they are found, scattered through the several funiculi to the lower level of the popliteal space.

Experiment No. 110.—Rabbit No. 93a; full grown; 96 days. September 4, 1918, right sciatic exposed; internal popliteal freed; resected 2.2 cm. A segment of equal length, taken from the right sciatic of a full-grown guinea pig, used as a transplant. One central and distal waxed, fine silk thread suture passed; good approximation. Wound closed. December 10, killed. Moribund; just breathing; much emaciated; severe neurotrophic ulcer right heel. On exposing the right sciatic, the external popliteal found free. Transplanted nerve segment found well in place, of small diameter, and shows several short stretches of yellow-white color. Large central bulb noted. Calf muscles exposed; these are atrophic and of pale yellow-red color. No contraction or twitching of muscles observed on cutting the nerve. Internal popliteal and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Only in part good differential silver staining attained.

Microscopic findings.—In longitudinal sections of the central wound region, a distinct central bulb evidenced structurally from the distal end of which down-growing neuraxes may be traced to the central end of the transplant and to the connective tissue by the side of the transplant. The series of cross sections of the transplant, torn and found not well differentiated. To one side there may be made out the necrotic remains of the transplanted nerves, occupying about one-half of the cross section area of the transplant, the remaining half consists largely of dense fibrous tissue in which small bundles of neuraxes are observed (this portion of the section is fragmented, so that relations are difficult to make out). In longitudinal sections of the distal wound region, new neuraxes in small numbers are seen to pass through the distal wound and to enter the central end of the distal popliteal, in which they extend for a distance of about 1 cm. beyond the distal wound.

Experiment No. 111.—Rabbit No. 87; not quite full grown; 99 days. August 28, 1918, left sciatic exposed; internal popliteal bundle freed; resected 2.8 cm. A segment of equal length taken from the left sciatic of a large, full-grown guinea pig, used as transplant. One central and distal waxed, fine silk thread suture placed; good approximation. Wound closed. December 6, rabbit found dead in the morning; much emaciated; severe neurotrophic ulcer left heel; an encapsuled, sausage-shaped, cold abscess over left tendo Achillis. On exposing the left sciatic, external popliteal found free. Transplant found well in place, throughout of light yellow color, which clearly demarks it; small diameter. Large spindle-shaped central bulb. Calf muscles are atrophic and present the appearance of degenerated muscle. Internal popliteal and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good silver differentiation attained.

Microscopic findings.—In longitudinal sections of the central wound region, a large central bulb is recognized structurally, in the distal end of this a necrotic area, stained jet-black, interpreted as the central end of the transplant, by the side of this area numerous neuraxes grow distalward. In cross sections of the transplant in its mid region, the perineural sheath found materially thickened; to one side and within the fibrous sheath, a deeply stained black mass is found occupying about one-half of the cross area of the transplant and representing the necrotic remains of the transplanted nerves. To the other side, also within the fibrous sheath, there are found small groups of neuraxes, separated by strands of fibrous tissue; a few new neuraxes are to be observed in the region of the distal wound. These may be traced to the distal popliteal in which they are followed to the lower level of the popliteal space; the remainder of the distal popliteal found completely degenerated.

Experiment No. 112.—Rabbit No. 87a; not quite full grown; 99 days. August 28, 1918, right sciatic exposed; internal popliteal freed; resected 2.0 cm. A segment of equal length taken from the right sciatic of a full-grown guinea pig, used as transplant. One central and distal waxed, fine silk thread suture placed; good approximation. Wound closed. December 6, found dead in the morning; much emaciated; severe neurotrophic ulcer right heel. On exposing the right sciatic, external popliteal bundle found free. The transplant found well in place, of light yellow color; on it or in it there may be traced a fine nerve bundle. Large spindle-shaped central bulb noted. Both central and distal sutures clearly evident. Calf muscles atrophic. The internal popliteal and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Fair silver differentiation attained.

Microscopic findings.—In longitudinal sections of the central wound region, a large central bulb evidenced structurally, from the distal end of which new neuraxes may be traced to the central end of the transplant. In cross sections of the transplant, the perineural sheath found very materially thickened and blended with the surrounding connective tissue. Within this connective tissue sheath small bundles of neuraxes, separated by strands of fibrous tissue, are to be found; certain small funiculi of nerve fibers seen in the surrounding connective tissue. New neuraxes in relatively small numbers found in the region of the distal wound, and in the distal internal popliteal just distal. In the posterior tibial continuation only degenerated nerve fibers found.

Experiment No. 113.—Rabbit No. 92; large; full grown; 104 days. September 3, 1918, left sciatic exposed; internal popliteal freed and resected 2.2 cm. A segment of equal length taken from the left sciatic of a full-grown guinea pig, used as transplant; good approximation. Wound closed. December 17, killed. Rabbit much emaciated; snuffles; neurotrophic ulcer on left heel. On exposing the left sciatic, external popliteal found only loosely adherent to the operated internal popliteal. On internal popliteal large central bulb is noted. Transplant found well in place, distal two-thirds of light yellow color, with several glistening white streaks. Central end of distal popliteal found distinctly enlarged. Calf muscles found atrophic, do not respond on cutting nerve centrally. Internal popliteal and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Imperfect silver differentiation attained.

Microscopic findings.—In series of longitudinal and cross sections taken at successive levels, the transplant clearly demarked by reason of its jet-black, nontransparent staining. The neuraxes of the central stump not clearly differentiated and for the remainder of the series not differentiated.

Experiment No. 114.—Rabbit No. 92a; large; full grown; 104 days. September 3, 1918, right sciatic exposed and internal popliteal freed; resected 2.0 cm. A segment of equal length taken from the right sciatic of a full-grown guinea pig, used as a transplant. One central and distal waxed, silk thread suture placed; central approximation good; distal suture pulled out; an epineural stitch made. Wound closed. December 17, killed. Rabbit much emaciated; snuffles; neurotrophic ulcer on right heel. On exposing right sciatic, external popliteal bound only loosely to operated internal popliteal. The internal popliteal presents a large central bulb. The transplant found well in place; of small diameter and in the main of light yellow color. Several small bundles of nerve appear to run on or in the transplant to reach the distal popliteal. Calf muscles atrophic; do not respond on cutting the nerve centrally. Internal popliteal and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Imperfect silver differentiation attained; sections light yellow color, with neuraxes not differentiated.

Microscopic findings.—The results of this experiment can not be clearly determined from study of sections. In cross sections of the transplant, small areas, which are quite certainly small funiculi of nerve fibers, found in the fibrous tissue to one side of the transplant; the region of the nerve fibers of the transplant only necrotic tissue made out. No neuraxes differentiated in the distal popliteal.

Experiment No. 115.—Rabbit No. 91; large; full grown; 191 days. September 2, 1918, left sciatic exposed; internal popliteal freed; resected 2.6 cm. A segment of equal length taken from a large full-grown guinea pig, 12 minutes after it stopped breathing, used as transplant. One central and distal waxed, fine silk thread suture passed; good approximation. Wound closed. March 12, 1919, killed. Rabbit in good condition; slightly emaciated; old neurotrophic ulcer on left heel nearly healed. A large, encapsuled, cold abscess found over tendo Achillis; this does not involve deeper tissues. On exposing the left sciatic the external popliteal found free; cutting of the nerve does not cause contraction of the muscles supplied by it. The operated internal popliteal bundle presents a large central bulb; transplant found well in place but of small diameter. Calf muscles found atrophic and do not respond on cutting nerve central to the transplant. Internal popliteal removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good silver differentiation attained.

Microscopic findings.—In longitudinal sections of the central wound region, long spindle-shaped bulb evidenced structurally from the distal end of which numerous down-growing

neuraxes are found to enter the central end of the transplant. In cross sections of the transplant the fibrous tissue sheaths of the nerves transplanted are found materially thickened. Numerous new neuraxes are found within the transplant, in the form of very small bundles separated by fibrous tissue. Only relatively few nerve fibers or neuraxes found in the surrounding fibrous tissue. Within the transplant only here and there necrotic remains of the transplanted nerve fibers found. Down-growing neuraxes traced to the distal wound and into the distal popliteal, in which they are found in good numbers at the lower level of the popliteal, the extent of the sections cut. The calf muscles were not studied in this experiment.

Experiment No. 116.—Rabbit No. 91a; large; full grown; 191 days. September 2, 1918, right sciatic exposed; internal popliteal freed; resected 3 cm. A segment of equal length taken from the right sciatic of a large guinea pig, which had stopped breathing 45 minutes previous, was used as transplant. One central and distal waxed, fine silk thread suture placed; good approximation. Wound closed. March 12, 1919, killed. Rabbit in good condition; old neurotrophic ulcer on right heel nearly healed. On exposing right sciatic, external popliteal found free. Large central bulb noted on the operated internal popliteal. Transplant found well in place, of good size, and presenting the appearance of a small nerve bundle. The distal internal popliteal presents the appearance of a normal nerve. External popliteal cut and resected and internal popliteal freed from bed. Calf muscles exposed. On slowly cutting with scissors operated nerve central to the transplant, vigorous contraction of the calf muscles observed; same on cutting distal to the transplant. The internal popliteal and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining; portions of the calf muscles removed for gold chloride staining. Fair differential silver staining attained.

Microscopic findings.—In longitudinal sections of the central wound region numerous neuraxes are observed to extend from the distal end of a large central bulb to the central end of the transplant. In cross sections of the transplant, in its mid region, the fibrous tissue sheaths of the nerve transplanted are found very materially thickened. Within the fibrous tissue sheaths numerous new neuraxes are found in the form of small bundles, separated by connective tissue. In the distal end of the central bulb and at several levels in the transplant areas of granular detritus, vesicular cells with globular and granular inclusions are to be found; remains of the transplanted nerves. New neuraxes traced to and through the distal wound into the central end of the distal popliteal. In gold chloride stained pieces of calf muscles numerous new neuraxes are found in the larger nerve bundles of the muscle and followed into the smaller interfascicular branches, but motor end plates were not found differentiated; teased muscle fibers presented normal appearance.

Experiment No. 117.—Rabbit No. 90; full grown; 194 days. August 30, 1918, left sciatic exposed; internal popliteal freed; resected 2.5 cm. A segment of equal length, taken from the left sciatic of a large guinea pig, which had stopped breathing 12 minutes previously, used as a transplant. One central and distal waxed, fine silk thread suture placed; centrally good approximation; distally "fair." Wound closed. March 12, 1919, killed. Rabbit in good condition; severe neurotrophic ulcer left heel, which appears to be healing. On exposing the left sciatic, external popliteal found free. Operated internal popliteal presents a large central bulb. Transplant in place as a fine strand extending from central bulb to the distal popliteal. Distal popliteal does not appear degenerated. On exposing the calf muscles these are found atrophic and of light yellow-red color. External popliteal removed and internal popliteal and transplant freed from bed. On slowly cutting with scissors nerve central to the transplant feeble to distinct contraction of the calf muscles observed. Internal popliteal and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained; sections somewhat torn.

Microscopic findings.—In longitudinal sections of the central wound region including the central end of the transplant numerous new neuraxes can be traced from the central bulb into the transplant and into the surrounding tissue. In cross sections of the transplant the transplanted nerve segment is recognized by its distinctly thickened fibrous sheaths, within which numerous new neuraxes may be seen. Scarcely any necrotic remains of the transplanted nerve observed. In the fibrous tissue surrounding the transplanted nerve segment there are to be seen many small funiculi of nerve fibers. Down-growing neuraxes can be traced through

the central wound into the central end of the distal popliteal, in which they are found in relatively large numbers in its several funiculi.

Experiment No. 118.—Rabbit No. 90a; full grown; 194 days. August 30, 1918, right sciatic exposed; the internal popliteal freed; resected 2.3 cm. A segment of equal length taken from the right sciatic of a full grown guinea pig, which stopped breathing 32 minutes previous, used as transplant. One central and distal waxed, fine silk thread suture placed; good approximation. Wound closed. March 12, 1919, killed. Rabbit in good condition; severe neurotrophic ulcer right heel. On exposing the right sciatic external popliteal found free. The operated internal popliteal presents a large central bulb. The transplant found in place; its distal half of light brown color. Calf muscles atrophic. Cutting of nerve central to transplant causes no contraction of the calf muscles. Internal popliteal and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Very good silver differentiation attained.

Microscopic findings.—In longitudinal sections of the central wound region, including the central end of the transplant, numerous neuraxes can be traced from the central bulb to the central end of the transplant and surrounding connective tissue. In the distal end of the central bulb, the neuraxes are found to cross and intercross central wound region. In cross sections of the transplant, about 1 cm. distal to central wound, the perineural sheaths of the transplanted nerve segments evident and not materially thickened; within these sheaths numerous neuraxes are observed. Outside of the perineural sheaths an area of connective tissue is observed in which there are found numerous small funiculi of nerve fibers. Downgrowing neuraxes can be traced through the transplant and from the surrounding connective tissue to the distal wound and through this to the distal popliteal stump in which, in the several funiculi, they are found in relatively large numbers.

Experiment No. 119.—Rabbit No. 95; full grown; 277 days. September 6, 1918, the left sciatic exposed; internal popliteal freed; resected 2.7 cm. A segment of equal length taken from the left sciatic of a full-grown guinea pig, used as a transplant. One central and distal waxed, fine silk thread suture placed; central approximation good; distal approximation, nerve ends not in good alignment. Wound closed. June 10, 1919, rabbit found dead in the morning; very much emaciated; severe neurotrophic ulcer left heel. On exposing the left sciatic the operated internal popliteal is found to end in a large central bulb, from the distal end of which no transplant nor nerve bundles can be traced to the distal popliteal, the central end of which ends free and presents an S-shaped curve. It would appear that the central suture gave way soon after the operation and that the transplanted nerve segment had completely disappeared. Calf muscles found atrophic and distal internal popliteal completely degenerated. Central bulb and distal internal popliteal removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good silver staining attained.

Microscopic findings.—In longitudinal sections of the central bulb this is found to include the central end of the transplant, consisting of necrotic detritus. Active downgrowth of central neuraxes is evident; these are lost in the surrounding connective tissue. In the distal popliteal the nerve fibers found completely degenerated.

Experiment No. 120.—Rabbit No. 95a; full grown; 277 days. September 6, 1918, right sciatic exposed; internal popliteal freed; resected 2.5 cm. A segment of equal length taken from the sciatic of a large, full-grown guinea pig, used as transplant. One central and distal waxed fine silk thread suture placed; very good approximation. Wound closed. June 10, 1919, rabbit found dead in the morning; very much emaciated; severe neurotrophic ulcer right heel. On exposing the right sciatic, the operated internal popliteal found to end in a large spindle-shaped bulb; the transplant well in place and of good size. Conditions of calf muscles not recorded. Internal popliteal and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Fair silver differentiation attained.

Microscopic findings.—In longitudinal sections of the central wound region a large central bulb, with characteristic structure of neuroma, including spiral neuraxes, evidenced structurally. In distal end of bulb, the necrotic remains of the central end of the transplant are found. Numerous down-growing neuraxes pass by the side of this necrotic area and extend distalward in the connective tissue. In the several successive series of sections the greater part of the transplanted nerve fibers, or the remains of the same, stained jet-

black in the silver. In cross sections of the transplant taken from its mid region small funiculi of nerve fibers are found in the connective tissue surrounding the transplant. In the region of the distal wound and in sections of the central end of the distal popliteal only a few neuraxes are to be observed; the greater part of the distal popliteal showing degenerated nerve fibers.

Experiment No. 121.—Rabbit No. 94; large Belgian hare; 358 days. September 5, 1918, left sciatic exposed; internal popliteal freed; resected 2.5 cm. A segment of equal length taken from the left sciatic of a large guinea pig and used as transplant. One central and distal waxed fine silk thread suture passed. Centrally "fair" approximation attained; distally good alignment, but cut nerve ends not quite end to end. Wound closed. August 28, 1919, rabbit in good condition; still large neurotrophic ulcer left heel; appears to be healing; spreads toes of left hind foot when held up by ears. On exposing the left sciatic external popliteal is found in close apposition to the operated internal popliteal; adherent to it. Large spindle-shaped central bulb on the operated internal popliteal. Transplant found well in place and presents the appearance of a normal nerve. Calf muscles exposed and external popliteal cut at the level of head of fibula; internal popliteal and transplant freed. On slowly cutting with scissors, central sciatic, good contraction of calf muscles and less vigorous contraction of the plantar foot muscles observed. Calf muscles found of nearly normal size and of pale red color streaked with yellow. The internal popliteal and transplant, portions of calf and foot muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Quite good differential silver staining attained.

Microscopic findings.—In longitudinal sections of the central wound region, from the distal end of the large central bulb, certain down-growing neuraxes can be traced into the central end of the nerve transplant, the majority into the connective tissue surrounding the transplant. In the connective tissue the small bundles of nerve fibers present a very serpentine course. In cross sections of the transplant, taken about 1 cm. distal to the central wound, numerous small funiculi of nerve fibers are found in the connective tissue surrounding the transplant, outside of the perineural sheaths. Within the transplant crosscut neuraxes, differentially stained, are found in good numbers, separated by strands of connective tissue. Only small remnants of the necrotic remains of the transplanted nerve fibers found within the transplant. Down-growing neuraxes can be traced to and through the distal wound, into the distal popliteal, in which they are found in good numbers in all of the funiculi. In sections of the calf muscles new neuraxes are found in the larger and smaller intramuscular nerve branches and as single fibers between and on the muscle fibers.

Experiment No. 122.—Rabbit No. 94a; large Belgian hare; 358 days. September 5, 1918, right sciatic exposed; internal popliteal freed; resected 2.5 cm. A segment of equal length taken from the right sciatic of a large, full-grown guinea pig, used as transplant. One central and distal waxed silk thread suture placed; good approximation. Wound closed. August 28, 1919, killed. Rabbit in very good condition; still large neurotrophic ulcer right heel, which appears to be healing. On exposing the right sciatic, the external popliteal is found free. A long spindle-shaped bulb found on the central internal popliteal. Transplant found well in place, of small diameter but presents the appearance of a normal nerve. Distal popliteal; looks like a normal nerve. Calf muscles exposed; very nearly of normal size and of pale red color streaked with light yellow. After cutting and resecting external popliteal and freeing the operated internal popliteal from bed, on slowly cutting nerve with scissors, central to the transplant, distinct but feeble contractions in the calf muscles noted; foot muscles uncertain. Functional test 20 minutes after the animal was killed. Internal popliteal and transplant and portions of calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining.

Microscopic findings.—Only in part good silver differentiation attained; in part fine granular silver deposit in sections. In longitudinal sections of the central wound region large numbers of down-growing neuraxes can be traced from the distal end of the central bulb to the central end of the transplant and the connective tissue surrounding the transplant; the latter in the form of numerous small funiculi, very much coiled and twisted; those entering the transplant follow a more regular longitudinal course after having passed the central

wound region. In cross sections of the transplant, about 1 cm. distal to the central wound, it may be observed that new neuraxes are found both within and without the perineural sheaths of the nerve segment transplanted. New neuraxes can be traced through the distal wound into the distal popliteal, in which they are found in good numbers in all of the funiculi. In the sections made from the calf muscles neuraxes are found in the larger fasicular nerve bundles and here and there as single nerve fibers on the muscle fibers. The muscle fibers so far as can be determined in silver stained preparations appear to present normal structure; here and there areas or columns of fat cells within the muscle.

Experiment No. 123.—Rabbit No. 78a; large; full grown; 7 days. June 3, 1918, right sciatic exposed; fascial plane not readily found, consequence muscle torn; sciatic resected 2.5 cm. A segment of equal length taken from the right external popliteal of a full-grown dog; nerve resected two hours previous; nerve segment lying in the wound used as transplant. One central and distal waxed fine silk thread suture placed; good approximation. Ultimately dry field; wound closed. June 10, rabbit found dead in the morning; superficial wound healed; deep wound congested. In deep wound near distal suture a small hematoma in the connective tissue. Transplant found well in place; united to the resected nerve ends; central and distal sutures distinct. Sciatic and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Faint but differential silver staining attained.

Microscopic findings.—Transplant united to central sciatic only at one border; for the remainder of the cross section separated by an appreciable distance. Distally good fibrous union obtained. In longitudinal sections of the transplant the neuraxes of the transplanted nerve fibers found fragmented into relatively long segments, having a wavy or spiral course, and stained differentially in the silver stain. The neurolemma sheaths seem well maintained, the perineural sheaths not appreciably thickened. In the distal end of the central sciatic stump early stages of the downgrowth of the central neuraxes evident. The nerve fibers of the distal sciatic present early stages of degeneration.

Experiment No. 124.—Rabbit No. 75a; full grown; 13 days. May 10, 1918, right sciatic exposed and resected 2.5 cm. A segment of equal length, taken from the left internal popliteal of a dog, used as transplant. One central and distal silk-thread suture placed; good approximation. Muscle stitched over nerve. Wound closed. May 23, rabbit found dead in the morning; "snuffles;" wound well healed. On exposing the right sciatic, transplant found well in place; appears of slightly greater diameter than when used; found well united to the resected nerve ends. Transplant surrounded by newly formed connective tissue. Sciatic and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential neuraxis staining attained.

Microscopic findings.—In longitudinal sections of the central and distal wound regions, ends of transplant found well united to the resected nerve ends. In longitudinal sections of the transplanted nerve segment, the neuraxes of the old nerve fibers are found segmented into longer and shorter segments, staining differentially in the silver stain; the neurolemma sheaths found well preserved; no distinct evidence of the proliferation of the sheath cells. Structural evidence of the beginning of a central bulb, from the distal end of which many down-growing neuraxes, terminating in bulbous end-discs, can be traced through the central wound for a short distance into the central end of the transplant. In certain of the neurolemma sheaths, near the central wound, remnants of old neuraxes and down-grown new neuraxes are to be found side by side. The fibers of the distal sciatic found in process of degeneration; many nucleated syncytial protoplasmic bands are seen, with proliferation of sheath cells.

Experiment No. 125.—Rabbit No. 76a; large; full grown; 52 days. May 17, 1918, right sciatic exposed and resected 2 cm. A segment of equal length, taken from the left ulnar of a dog, used as a transplant. One central and distal silk-thread suture passed; good approximation. Wound closed. July 8, rabbit found dead in the morning; wound well healed. On exposing the right sciatic, transplant was found to be well in place, firmly united to the resected sciatic stumps; adherent to the underlying muscle. Transplant of yellow-white color but seems of good consistency. No well-marked central bulb noted. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—In the successive series of longitudinal and cross sections, the transplanted nerve segment is clearly demarked by reason of a jet-black nontransparent coloring, the connective tissue sheaths being stained a yellow-brown color. Within the transplant, here and there fragments of neuraxes are found within the neurolemma sheaths. In cross sections of the transplant, wherever the dark coloring admits of the observation, in nearly every neurolemma sheath there may be observed the cut end of the old neuraxis. In longitudinal sections of the central wound region, down-growing neuraxes, traced from the distal end of the central bulb, may be seen passing by the side of the nerve transplant into the surrounding connective tissue, and in longitudinal sections of the transplant, new neuraxes are found in the fibrous tissue between the funiculi. No new neuraxes are found in the region of the distal wound. The nerve fibers of the distal sciatic are found completely degenerated.

It is evident from a study of the protocols of the experiments on hetero-nerve transplant, that on the face of the results attained the statement is warranted that a hetero-nerve transplant may be used to bridge a nerve defect with probability of success, to the extent that certain of the down-growing central neuraxes will penetrate the central end of the transplant and through it reach the distal segment. In all of the experiments of this series, kept for more than three months (No. 109 to No. 122) after the operation, the down-growing neuraxes derived from the distal end of the central stump could be traced into the central end of the transplant, to the distal wound region, and thence to the distal sciatic stump. There seems no question that a certain number of down-growing neuraxes, the number varying in the different experiments, reach the distal sciatic segment through the hetero-nerve transplant. Having established this general conclusion, the protocols of the experiments of long duration may be studied more critically, and it will be found that in nearly every record of microscopic findings it is noted that the down-growing neuraxes derived from the central stump not only penetrate the central end of the transplant but at the central wound region pass into the connective tissue surrounding the transplant and in close contiguity to it reach the distal wound and, perchance, enter the distal sciatic stump. These extrafunicular nerve bundles are most easily determined in cross sections of the transplant and surrounding connective tissue. In such sections, the funicular structure of the nerve transplanted is usually readily made out, even months after the operation, and the perineural sheaths surrounding the funiculi are evident. In properly stained sections, with neuraxis differentiation, extrafunicular nerve fibers, singly or in small bundles, are easily determined. Such extrafunicular fiber bundles usually have an irregular serpentine course, as though winding their way through the interstices of the connective tissue. It may also be noted that these extrafunicular nerve fiber bundles are on the whole much more numerous than is the case when auto- or homo-nerve transplants are used, and may include a relatively large per cent of the central nerve fibers reaching the distal wound and the distal nerve segment. It can also be shown that the rate of regeneration appears much slower when a hetero-nerve transplant is used than when using an auto- or homo-nerve transplant. Further, that the results are not so satisfactory, taking as an index the number of neuraxes which reach the distal stump through the hetero-nerve transplant, as when auto- or homo-nerve transplants are used. However, the hetero-nerve transplant does not become necrotic as is stated by certain observers. If properly sutured to the resected

nerve ends, the ends of the hetero-nerve transplant quickly form fibrous union with the resected nerve ends and become surrounded by newly formed connective tissue. In experiments terminated from six to twelve months after the operation, there is usually present a prominent central nerve bulb which includes the central wound region. In the region of the transplant the nerve bundle has the appearance of a living nerve, though of smaller diameter than when the nerve was transplanted. The hetero-nerve transplant has not disappeared, since months after the transplant was placed its funicular structure can be made out.

In the earlier stages of experimental operative work on nerve bridging no special consideration was given to the relative value of auto-, homo-, and hetero-nerve transplants; the need of making such differentiation was not recognized. As early as 1869, Philippeaux and Fulpian used a lingual nerve to bridge the resected hypoglossal nerve of dogs; auto-nerve transplant. These experiments were followed by others in which auto-, homo-, and hetero-nerve transplants were used, generally with indifferent or unfavorable results. Huber, in 1895, reported on a series of 26 experiments of nerve transplantation. Of this number in 10 of the experiments the animals were kept for a period of four months or more before the operated nerve was tested functionally and the nerve removed for examination. In five of these, all hetero-nerve transplants (cat's sciatic to resected ulnar of dog), the results were very satisfactory; in four others the down-growing central neuraxes had passed the region of the transplant and entered the distal nerve segment. With the microscopic methods available then, such precise neuraxis differentiation could not be had as now and it was not determined whether all of the down-growing neuraxes passed to the distal stump through the funiculi of the transplant or extra-funicular in the surrounding connective tissue. In an unsigned statement, found in the "Medical Supplement, Daily Review of Foreign Press," London, October 1, 1918, giving a review of the treatment of gun-shot injuries of nerves in Germany to the middle of 1917, the following statement appears:

> When a gap between the two divided nerve ends can not be obliterated, the unsettled question as to the regeneration of nerves has to be taken into consideration. The dominant view before the war was that regeneration in the peripheral segment was due entirely to the down growth of axis-cylinders from the proximal segment. But this theory does not seem to receive much confirmation. The regeneration of potential nerve fibers in the still separated distal segment, as described by Ballance and Purves Stewart, has found supporters, the potential nerve fibers becoming linked up with axis cylinders in the proximal segment when the two ends are brought together * * *. The second view that the distal segment regenerates so far affords encouragement to the method of inserting into the gap a nerve graft, which shall serve, as it were, to prolong the peripheral segment to meet the proximal end. Then the axis cylinders in the proximal segment, without growing out more than is seen in case of nerve end bulb, can become connected by a series of links with the potentially regenerated nerve fibers, and then these become fully developed. This nerve grafting to fill gaps gains support from animal experimentation and appears to be the plan which should be adopted in surgery.

The experimental observations on nerve transplantation furnish the most conclusive evidence for the monogenetic or downgrowth theory of nerve regeneration. In none of the experiments recorded under Series No. 5, No. 6, and No. 7 is there found any evidence in support of auto-regeneration of the

peripheral stump. In suitably stained pyridine-silver preparations of a nerve bridged by a nerve transplant and removed for study at the right time, in a serial order at progressive stated intervals, it can be seen that the budding central neuraxes grow to the region of the central wound and step for step into the transplant, through the transplant into and through the distal wound and into the distal segment, and in this progressively until the end organs are reached. As a result of the observations accumulated in this series of experiments, there is found abundant warrant for stating that the nerve bridge or nerve transplant offers a suitable path for down-growing central neuraxes and that regeneration of the distal segment after nerve bridging is only through down-growing central neuraxes.

In more recent experimental observations and in the more modern surgical work more precise recognition has been given to the relative merits of the auto-, homo-, and hetero-nerve transplants as with other tissue grafts. As a result of experimental observations, Forssman [70] and a little later Merzbacher,[71] whose results were confirmed by Segale,[72] were the first to suggest that there were important differences between homo- and hetero-nerve transplants. As a result of their observations it was concluded that in auto- and homo-nerve transplants the transplanted nerves survived and were capable of undergoing degenerative changes while a hetero-nerve transplant was subject to a necrobiotic process owing to the fact that it did not survive in the host. On the other hand, Maccabruni,[73] working in the laboratory of Golgi, found that there was little difference in the behavior of auto-, homo-, or heterogenous nerve segments transplanted into connective tissue or intermuscular septa, the axial portion of each becoming necrotic while the more peripheral portions, subject to better nutrition, presented the phenomena of nerve degeneration, even proliferation of sheath cells. Ingebrigtsen has considered this question in a number of contributions. In the account of 1915, [74] the following statement appears: "In the problem of transplantation of nerves the question of the fate and survival and multiplication of the cells of Schwann is of importance. The solution of this point, which is the only reliable sign of the survival of the transplanted piece, gives the key to the problem and will influence the procedure of surgeons in cases of nerve defects. If the grafts die and become necrotic they are no more suitable for bridges than strands of catgut." Writing in 1916, Ingebrigtsen [75] states that Wallerian degeneration occurs in auto- and homo-nerve transplants in the same manner as in the peripheral end of a cut nerve, except that the various changes take place somewhat slowly, while in hetero-transplants there is no Wallerian degeneration and no proliferation of sheath cells and 12 to 15 days after transplantation the nerve becomes necrotic and on histologic examination of the later stages no new neuraxes were found in the heterogenous transplant. After more extended study and in a comprehensive monograph (1918) [43] Ingebrigtsen had broadened his viewpoint, as may be noticed from the following quotation which is presented in this quite literal translation:

> And we come then to the conclusion that the cells of the sheath of Schwann of the auto- and homo-nerve transplants are without biological significance whatever for the regeneration of the new neuro-fibrils of the transplant, which grow into the transplant from the central stump whether the transplant is living or dead.

In the extended series of operations on nerve transplants, included in Series No. 5, No. 6, and No. 7, auto-, homo-, and hetero-nerve transplants, primary consideration was given to the downgrowth of central neuraxes in regeneration and their relation to the transplanted nerve fibers, and for this purpose the pyridine-silver neuraxis differentiation method was largely used. This method is not suitable for a detailed study of the myelin fragmentation nor the behavior of the sheath cells of the transplanted nerves. The evidence at hand warrants the conclusion that none of the transplanted nerve fibers, whether of auto-, homo-, or heterogenous source, undergo typical Wallerian degeneration, if sheath cell proliferation is to be considered a sine qua non of Wallerian degeneration. Further, the conviction has been gained that the sheath cells of the transplant play a very subsidiary and a negligible rôle as concerns regeneration through a nerve transplant. (Series No. 11, No. 12, and No. 13 seem to demonstrate this conclusively.) That there is a difference in the behavior of auto- and homo-nerve transplants on the one hand, and hetero-nerve transplant on the other there can be no question. However, one can not accept the statement that heteroplastic nerve transplants become necrotic. Months after such a transplant has been placed, can its funicular structure be determined, with funiculi surrounded by perineural sheaths? That regeneration may take place through a hetero-nerve transplant the earlier observations of Huber (1895) [30] may serve to show, as also certain of the experiments of longer duration of Series No. 7. In preparations made from this series the neuraxes were differentially stained by the pyridine-silver method and in successful preparations stained by this method there is no difficulty in determining neuraxes. The results obtained as regards regeneration of the peripheral segment are not nearly so favorable on use of the heterogenous transplant as when auto- and homo-nerve transplants are used. However, this would seem to be due not so much to a difference in the mode of fragmentation of the myelin and a want of sheath cell proliferation but to a relatively retarded and at times imperfect phagocytosis of the products of myelin fragmentation, leaving the neurolemma tubes less suitable for neuraxis downgrowth than when homo- or auto-nerve transplants are used. The answer to the question of chemotactic or want of chemotactic action of the products of nerve degeneration and sheath cell proliferation can not now be given, since sufficient and conclusive experimental evidence is not now at hand. Conditions being approximately equal as concerns operation, relative size of nerve and sutures, the extrafunicular nerve fibers coming from the central stump and passing into the connective tissue surrounding the transplant are much more numerous when heterogenous transplants are used than with autogenous or homogenous transplants. This is interpreted as an index that the latter are more favorable than the former for downgrowth of neuraxes. Thus, while the regeneration of the distal segment of a resected nerve can be obtained through a heterogenous nerve bridge in experimental work, the outcome is less certain and less satisfactory and it requires a longer time than when auto- or homo-nerve transplants are used. Thus, hetero-nerve transplantation is not recommended as an operation in the repair of human nerves after loss of nerve substance.

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DEGENERATED NERVE TRANSPLANTS

SERIES NO. 8, NO. 9, AND NO. 10

DEGENERATED AUTO-, HOMO-, AND HETERO-NERVE TRANSPLANTS

In Series No. 8, No. 9, and No. 10, including degenerated auto-, homo-, and hetero-nerve transplants, the nerve segment selected for the transplant was taken from a nerve which had been caused to undergo Wallerian degeneration as a result of nerve section some weeks before the nerve segment was used as a nerve bridge. This series of experiments was undertaken to test a number of hypotheses relative to nerve transplants. It was conjectured that since a transplanted nerve segment degenerates after transplantation, the process of regeneration through a nerve transplant might be facilitated by using a nerve segment already degenerated to the extent of presenting the nucleated syncytial strands ("bandfasern") in the neurolemma sheaths. In a measure one may regard the nucleated syncytial strands, the product of sheath cell proliferation, as less differentiated protoplasm than developed sheath cells, conceivably a protoplasm more favorable to downgrowth of central neuraxes. Especially was it conjectured that a degenerated hetero-nerve transplant might for this reason prove more satisfactory than a hetero-nerve transplant taken from a normal nerve. It was further felt, consequent to the suggestion of certain observers who have regarded degenerating nerve fibers and proliferating sheath cells as capable of exerting a chemotactic influence on down-growing neuraxes in nerve regeneration, a degenerated nerve transplant might serve to attract, from the beginning of transplantation, central neuraxes in early stages of regeneration. None of these suppositions were well founded. These three series of experiments are jointly presented and considered. The protocols of experiments 126 to 149 (Series No. 8, No. 9, and No. 10) are as follows:

PROTOCOLS

Experiment No. 126.—Dog No. 1; medium size; full grown; 133 days. March 25, 1918, right ulnar exposed and resected 1.2 cm. As a transplant, used 1.2 cm. of the distal segment of the left sciatic of the same dog, cut March 7, 18 days previous. One central and one distal Chinese silk suture placed; good approximation. Quite a little bleeding, which was not fully controlled. Fascia stitched over the nerve and transplant. Wound closed. August 5, killed. Dog in good condition. On exposing the ulnar, the transplant was found well in place; easily demarked, since central and distal sutures are still clearly evident. Transplant has diameter slightly larger than ulnar. Ulnar distal to transplant presents the appearance of normal nerve. Forearm muscles supplied by ulnar do not contract when ulnar is cut central to the transplant. Ulnar and the transplant and distal ulnar removed and fixed in ammoniated alcohol. Only in part good differential staining attained. Tissues not well embedded, sections torn.

Microscopic findings.—In longitudinal sections of the central wound region, distinct central bulb evidenced structurally, from the distal end of which down-growing neuraxes can be traced to the transplant. In cross sections of the transplant, the funicular structure of the degenerated nerve segment transplanted, is in part retained. New neuraxes observed in the funiculi, in which they are arranged in small bundles separated by fibrous tissue; also in the connective tissue surrounding the transplant; especially to one side. In longitudinal sections of the distal wound region, new neuraxes can be traced to the distal ulnar and in this, in good numbers to the level of the elbow; the extent of the distal ulnar segment sectioned.

EXPERIMENT No. 127.—Dog No. 3; medium size; full grown; 134 days. March 27, 1918, right ulnar exposed and resected 1.5 cm. A segment of equal length, taken from the external popliteal bundle of the left sciatic of the same dog, cut March 8, 18 days previously, used as transplant. One central and distal Chinese silk suture placed; fair approximation attained. Free venous bleeding, not fully controlled. Fascia stitched over nerve; wound closed. August 8, killed. Dog in very good condition. On exposing the right ulnar, a large bulb is observed on end of central ulnar stump, from which a small nerve bundle leads to the distal ulnar segment. On cutting ulnar central to the transplant, no distinct contraction of the forearm mucles supplied by the ulnar is observed. Ulnar and transplant and segment of distal ulnar removed and fixed in ammoniated alcohol for pyridine-silver staining. Not entirely successful silver differentiation attained.

Microscopic findings.—In alternate longitudinal and cross sections, new neuraxes can be traced from the central ulnar stump to the distal ulnar. In the cross sections taken from the middle of the transplant, the funicular structure of the transplanted nerve segment not clearly made out. Small funiculi of nerve fibers are observed. Their relation to the transplanted nerve segment is uncertain.

EXPERIMENT No. 128.—Dog No. 2; medium size; full grown; 420 days. March 26, 1918, right ulnar exposed and resected to the extent of 1.5 cm. A segment of equal length taken from the left external popliteal of the same dog, the left sciatic of which was cut March 7, 19 days previous, used as a transplant. One central and distal Chinese silk suture placed; good approximation. Fascia stitched over nerve; wound closed. May 20, 1919, killed. Dog in good condition. On exposing the right ulnar, distinct central ulnar bulb is found, from the distal end of which a well-formed bundle of nerves, of slightly smaller diameter than the ulnar, leads to the distal ulnar stump, the central end of which is only slightly enlarged. In the region of the transplant nerve firmly adherent to the surrounding tissue, the distal ulnar has the appearance of a normal nerve. After exposing the forearm muscles, and freeing the ulnar from its bed, on slowly cutting the ulnar central to the transplant, distinct and vigorous contraction of the forearm muscles supplied by the ulnar. Ulnar and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Micrsocopic findings.—In series of alternate longitudinal and cross sections, through transplant and distal ulnar, neuraxes coming from the central ulnar can be traced through the transplant into the distal ulnar. In cross section of the transplant, taken at its middle, it may be clearly seen that the connective tissue of the transplant is very materially increased; this blending with the perineural sheaths. Certain of the down-growing neuraxes, both myelinated and nonmyelinated, appear within a large funiculus of the transplanted nerve segment. Others are found in small bundles in the connective tissue outside of the transplant. In the distal ulnar, cut in cross sections 2 cm. below the elbow, both myelinated and nonmyelinated neuraxes are found scattered through all of the funiculi, in large numbers.

EXPERIMENT No. 129.—Dog No. 36; medium size; full grown; 17 days. June 4, 1918, left sciatic exposed; internal popliteal bundle freed and resected 3 cm. A segment of equal length, taken from the left internal popliteal of dog No. 24, the sciatic of which was cut May 18, 17 days previous, used as a transplant. One central and distal waxed, fine silk thread suture placed; very good central and distal approximation attained. Wound closed. June 21, dog found dead in the morning; no neurotrophic changes of left hind foot. On exposing the left sciatic, transplant is found well in place, and appears of slightly larger diameter than when transplanted; no distant central bulb observed. The internal popliteal and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—In longitudinal sections of the central and distal wound regions, transplant found well united to resected nerve ends with only narrow fibrous tissue union intervening. Scarcely any evidence of central bulb noted. In the distal end of the central stump, active outgrowth of central neuraxes observed. These have reached the scar tissue of the central wound, which many have penetrated and which they traverse by crisscrossing in all directions. Many end-discs and evidence of branching of neuraxes seen. A certain few of the central neuraxes have passed through the central wound into the central end of

the nerve transplant. These are much more numerous near the central wound than a little more distally, but can be traced to nearly the middle of the transplant. Within the transplant there are observed the thickened neurolemma sheaths of the degenerated, transplanted nerve fibers, and remnants of myelin. The distal internal popliteal is found in early stage of degeneration.

Experiment No. 130.—Dog No. 7; large; full grown; 36 days. July 5, 1918, left sciatic exposed; internal popliteal bundle freed; resected 4 cm. A segment of equal length, taken from the left internal popliteal of dog No. 28, the sciatic of which was cut 28 days previously, used as a transplant. One central and distal waxed, fine silk thread suture placed; very good approximation attained. Wound closed. August 10, killed. Dog seemed well, though emaciated; no neurotrophic changes left hind foot; wound well healed. On exposing the left sciatic, the external popliteal bundle found free; the transplant in the internal popliteal well in place, and clearly demarked by its light yellow color; no material increase of connective tissue about the transplant. No distinct central bulb noted. The internal popliteal removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht-grün.

Microscopic findings.—In longitudinal sections of the central and distal wound regions, transplant found well united to the resected nerve ends; fibrous tissue union at the wounds. In the sections from the central wound region, new nerve fibers, in part with fine myelin sheaths, can be traced from the central stump, through the central wound into the transplant. In cross and longitudinal sections of the transplant, the neurolemma sheaths found give the impression of being thickened. Many of these sheaths contain large vesicular cells, having globular, myelin remains in their protoplasm; further, granular detritus; not many sheath nuclei evident. The distal nerve presents degeneration phenomena.

Experiment No. 131.—Dog No. 5a; large; full grown; 37 days. July 3, 1918, the right sciatic exposed; internal popliteal freed; resected 3.4 cm. A segment of equal length taken from the internal popliteal of the right sciatic of dog No. 27, cut June 6, 27 days previous and used as a transplant. One central and distal waxed fine silk thread suture placed; good alignment attained, but distal end of transplant rotated; good approximation of nerve ends. Wound closed. August 9, killed. Dog emaciated; small neurotrophic ulcer right hind foot. Wound well healed. On exposing the right sciatic, it is found that the external popliteal is closely adherent to the operated internal popliteal; was not dissected free. Distinct increase of connective tissue in the region of operation, about the sciatic. The transplant found well in place; demarked by its light yellow color. No distinct central bulb noted. External and operated internal popliteal bundle removed together and fixed in ammoniated alcohol for pyridine-silver staining. Good differential neuraxis staining attained.

Microscopic findings.—In longitudinal sections of the central wound region neuraxes from the central stump in large numbers can be traced into the central end of the transplant. In cross sections of the transplant, 1 cm. distal to the central wound, numerous neuraxes are found within the transplant, in the form of small bundles, separated by strands of fibrous tissue. In longitudinal sections of the transplant, it may be observed, that while these small bundles have in the main a longitudinal direction, contiguous bundles frequently are found anastomosing. Only a small number of old myelin remnants are found in the transplant. A few of the down-growing neuraxes have reached the distal wound and can be traced for a short distance into the central end of the distal popliteal; by far the greater portion of the distal popliteal showing only degenerated nerve fibers.

Experiment No. 132.—Dog No. 37; medium size; full grown; 146 days. June 18, 1918, left sciatic exposed; internal popliteal freed, resected 2.7 cm. A segment of equal length, taken from the internal popliteal bundle of the left sciatic of dog No. 23, cut May 31, 18 days previous, used as transplant. One central and distal waxed fine silk thread suture placed; good approximation. Wound closed. November 11, killed. On this day participated in fight with another dog and nearly killed; was still breathing when found. Dog in good condition. No neurotrophic changes left hind foot noted. On exposing the left sciatic, external popliteal found free; no distinct bulb on central internal popliteal. Transplant found well in place, has the appearance of normal nerve, except that a light pink color is evident. Distal nerve has the appearance of normal nerve. Calf and the plantar muscles exposed and external popliteal resected and removed. After freeing the internal popliteal and

transplant from the bed, on slowly cutting the nerve central to transplant, good contraction of calf and interossei muscles observed. On cutting posterior tibial at heel, interossei muscles seen to contract. Internal popliteal and the transplant, posterior tibial, internal plantar and portions of several interossei muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential neuraxis staining attained.

Microscopic findings.—In longitudinal sections of the central wound region, a long spindle-shaped bulb evidenced structurally from the distal end of which numerous down-growing neuraxes can be traced to the central end of the transplant. In cross sections of the transplant 1 cm. distal to the central wound, the perineural sheaths of the transplant found thickened. Within these sheaths are found, within the funiculi, numerous small bundles of neuraxes, certain of which are myelinated, separated by strands of fibrous tissue. Large numbers of the neuraxes in these small bundles may be traced to and through the distal wound into the distal internal popliteal, in which new neuraxes are found in all of the funiculi. New neuraxes can be traced to the interfascicular nerve branches in the interossei muscles; a few motor ending observed. Good regeneration of the distal popliteal attained.

Experiment No. 133.—Dog No. 8a; large dog; full grown; 316 days. July 9, 1918, left sciatic exposed; internal popliteal freed; resected 3.8 cm. A segment of equal length, taken from the internal popliteal of the sciatic of dog No. 26, cut June 7, 32 days previous, used as transplant. One central and distal waxed fine silk thread suture placed. Good distal approximation; central good alignment, but after tying distal suture, central suture gave way slightly, so that nerve ends were nearly 2 mm. apart. Wound closed. May 21, 1919, killed. Dog in very good condition; uses left hind foot well; no neurotrophic changes. On exposing the left sciatic, the external popliteal is found free. No distinct enlargement on central internal popliteal noted. The transplant found well in place and presents the appearance of a normal nerve, though somewhat spread out and of flattened form. Distal popliteal has the appearance of a normal nerve. Calf and plantar muscles exposed; external popliteal resected and removed. After separating nerve and transplant from bed, on slowly cutting nerve with scissors central to the transplant, distinct and vigorous contraction of calf and foot muscles noted. Internal popliteal and transplant, posterior tibial, portions of calf and foot muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential neuraxis staining attained.

Microscopic findings.—In longitudinal sections of the central wound region, quite distinct spindle-shaped bulb evidenced structurally, from the distal end of which numerous neuraxes enter the transplant. In cross sections of the transplant, taken at levels near the central and distal wounds, the transplanted nerve segment found to be well outlined with thickened fibrous sheaths. Within the transplant are found numerous small bundles of neuraxes separated by strands of fibrous tissue. Numerous small bundles of neuraxes also found in the connective tissue surrounding the nerve transplant. Many of the neuraxes within and without the transplant are found to be myelinated. New neuraxes can, in sections made at successive levels, be traced through the transplant into and through the distal wound into the distal popliteal, in which they are followed to the interossei muscles. In sections of portions of the interossei muscles, new nerve fibers may be observed in interfascicular nerve branches and as single nerve fibers, on and between muscle fibers. Motor endings found not well differentiated. Nearly complete regeneration of the distal popliteal observed.

Experiment No. 134.—Rabbit No. 78; large; full grown; 7 days. June 3, 1918, left sciatic exposed and resected 2.5 cm. A segment of equal length, taken from the external popliteal of dog No. 21, the left sciatic of which was cut 16 days previous, used as transplant. One central and distal waxed fine silk thread suture placed; good approximation. Wound closed. June 10, rabbit found dead in the morning. Wound well healed. On exposing the sciatic, tissues about the nerve found congested. Transplant found well in place, though distal suture had drawn out a little. Transplant united to resected nerve ends; good color. Sciatic and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good silver differentiation of neuraxes attained.

Microscopic findings.—In longitudinal sections of the central wound region the very early stages of a bulbous end on central sciatic stump noted. Certain of the larger neuraxes

of the central stump present large, bulbous ends; growing end-discs noted just central to central wound. Central wound consists of loose fibrocellular tissue, coagulum, and tissue detritus. In longitudinal sections of the transplant, remnants of old neuraxes, in the form of short segments, twisted, coiled, or bent, are to be observed. Faintly stained nuclei are found within the old neurolemma sheaths. In the distal sciatic beginning of nerve degeneration observed.

Experiment No. 135.—Rabbit No. 75; full grown; emaciated; 13 days. May 10, 1918, left sciatic exposed and resected 2.5 cm. A segment of equal length, taken from the internal popliteal bundle of the left sciatic of dog No. 2, cut April 23, 17 days previous, used as transplant. One central and distal waxed, fine silk thread suture passed; good approximation. Wound closed. May 23, rabbit found dead in the morning; snuffles; wound well healed. On exposing the left sciatic, transplant found well in place; demarked by sutures. Transplant seems of slightly larger diameter than when used, and found surrounded by newly formed connective tissue. Beginning of bulbous enlargement on the distal end of the central stump. Sciatic and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Very good differential staining, especially central stump, attained.

Microscopic findings.—In a series of longitudinal sections of the central wound region, distinct bulbous end of central stump evidenced structurally, at the distal end of which is found the wound line, consisting of fibrocellular tissue; suture found in sections. Many down-growing neuraxes of the central stump have reached the wound line. Many of these show bulbous end-discs; certain of them are directed centralward, others toward the periphery. In longitudinal sections of the transplant, the fibrous tissue sheaths are found very materially thickened by means of newly formed connective tissue containing many leucocytes. The neurolemma sheaths very materially thickened. These in longitudinal sections present a wavy zigzag course. Globules of myelin and remnants of neuraxes observed. Many wandering leucocytes are found between the old nerve fibers. The distal sciatic presents early stages of degeneration.

Experiment No. 136.—Rabbit No. 85; nearly full grown; Belgian hare; 42 days. July 9, 1918, left sciatic exposed and resected 2.2 cm. A segment of equal length, taken from the right median of dog No. 26, cut June 7, 32 days pervious, used as transplant. One central and distal suture of waxed, fine silk thread placed; approximation good, though the transplant has slightly greater diameter than the sciatic resected. Wound closed. August 20, rabbit found dead in the morning; very much emaciated; large neurotrophic ulcer on left heel. On exposing the left sciatic, the transplant is found well in place; of larger diameter than the resected nerve and of yellow-white color. No distinct central bulb noted. Transplant and suture lines surrounded by relatively dense fibrous tissue and adherent to underlying muscle. Sciatic and the transplant removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht-grün.

Microscopic findings.—In longitudinal sections of the wound regions, the resected nerve ends and ends of transplant found firmly united. There is noted a marked increase of fibrous tissue about the transplant. In longitudinal sections of the transplant, the neurolemma sheaths of the transplanted nerve fibers appear thickened and as if consisting of a delicate fibrillar structure. Near the central and distal wound leucocytes found within the neurolemma sheaths and here and there are found to contain globules. In cross sections of the transplant, about 1 cm. distal to the central wound, numerous small funiculi consisting of nonmyelinated fibers found in the connective tissue surrounding the transplant, outside of its perineural sheaths. Distal popliteal found in advance stages of nerve degeneration. Near the distal wound leucocytes found within the neurolemma sheaths of the distal popliteal.

Experiment No. 137.—Rabbit No. 77; full grown; 48 days. May 20, 1918, left sciatic exposed and resected 2.2 cm. A segment of equal length taken from the right ulnar of dog No. 22, cut April 29, 21 days previous, used as transplant. One central and distal fine Chinese silk thread suture placed; good approximation. Wound closed. July 7, rabbit found dead in the morning; neurotrophic changes left heel. On exposing the left sciatic, transplant is found well in place, of light yellow color, of slightly smaller diameter distally and surrounded

by a relatively firm layer of fibrous tissue. Only slight evidence of bulbous enlargement of central sciatic noted. Distal sciatic presents the appearance of a normal nerve. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining.

Microscopic findings.—In series of longitudinal and cross sections taken at successive levels, nearly the entire nerve transplant is very clearly demarked by reason of a peculiar silver reaction. Exclusive of the perineural sheaths, and the nerve fibers immediately adjacent, the entire transplant is stained a jet-black, making it nontransparent even in sections of 5 microns thickness, so that no structure can be made out in the parts thus stained. In longitudinal sections of the central wound region, numerous neuraxes growing from the central nerve can be traced through the wound tissue to the beginning of the transplant, but appear to pass no distance into the transplant. Certain of these neuraxes deviated to one side and may be traced for a distance of several millimeters in the connective tissue sheath surrounding the transplant. Distal sciatic degenerated.

Experiment No. 138.—Rabbit No. 77a; full grown; 48 days. May 20, 1918, right sciatic exposed and resected 2.2 cm. A segment of equal length, taken from the right median of dog No. 22, cut April 29, 21 days previous, used as transplant. One central and distal fine Chinese silk thread suture placed; good approximation central; distal "fair." Wound closed. July 7, rabbit found dead in the morning; neurotrophic changes right heel. On exposing the right sciatic, transplant is found well in place, of light yellow color, of firm consistency; united to the resected nerve ends. No material increase of connective tissue found surrounding the transplant. Distinct central bulb noted. Distal sciatic presents the appearance of a degenerated nerve. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining.

Microscopic findings.—In longitudinal and cross sections taken at successive levels, transplant clearly demarked by reason of its jet-black color after silver staining. Neuraxes from the central sciatic may be observed to grow toward the central end of the transplant, but not to penetrate it. Certain of these neuraxes deviate to one side and can be traced distalward into the connective tissue sheath of the transplant. These relatively few neuraxes can be traced in the connective tissue sheath, in cross and longitudinal sections of the transplant to near the distal wound, where they escape the plane of section. Relatively few neuraxes are again recognized in the distal wound and for a distance of about 2 mm. in the central end of the distal sciatic stump, in longitudinal sections of which only ten to fifteen neuraxes are recognized in one section, all other nerve fibers included in the section degenerated.

Experiment No. 139.—Rabbit No. 76; large; full grown; 52 days. May 17, 1918, right sciatic exposed and resected 2 cm. A segment of equal length taken from the right ulnar of dog No. 21, cut April 29, 18 days previous, used as transplant. One central and distal fine Chinese silk thread suture placed; good approximation. Wound closed. July 8, rabbit found dead in the morning; severe neurotrophic changes right heel. On exposing the right sciatic an encapsuled abscess in the region of the transplant found. The transplant appears to have pulled free from distal stump and has almost completely disappeared; only a short segment, of light yellow color, adhering to central sciatic stump. Large bulbous end found on the distal end of central sciatic. Central sciatic and bulbous end removed and fixed in ammoniated alcohol for pyridine-silver staining. Very good silver differentiation attained.

Microscopic findings.—In two series of sections, the segment of the transplant remaining, clearly demarked by reason of its jet-black color. In longitudinal sections through the central bulb and contiguous central end of transplant, it is evident that there was not obtained an end-to-end suture of resected nerve end and transplant, the central end of the transplant having slipped to one side, so that the distal end of the central sciatic stump rests against the perineural sheath of the transplant. A well-developed central bulb is evidenced structurally from the end of which numerous neuraxes grow distalward; meeting the perineural sheath of the transplant, they are diverted from their course and form small convoluted bundles of nerve found in the surrounding connective tissue. Many of the central neuraxes end distally in large end-discs. In the bulb itself, just central to the wound region, numerous spirals composed of neuraxes may be observed. Central neuraxes can be traced distally for only a short distance. In cross sections of the transplant, 1 cm. distal to the central wound, no neuraxes are found in the connective tissue surrounding the transplant. The distal sciatic was found completely degenerated.

Experiment No. 140.—Rabbit No. 82; full grown; 62 days. July 8, 1918, right sciatic exposed and resected 2.6 cm. A segment of equal length taken from the external popliteal bundle of the left sciatic of dog No. 25, cut June 7, 31 days previous, used as a transplant. One central and distal waxed, fine silk thread suture placed; good approximation. Wound closed. September 8, rabbit found dead in the morning; very severe neurotrophic changes right hind foot; foot in part missing; "fungus" ears. On exposing the right sciatic, transplant is found well in place, of distinct yellow color, thus clearly demarked from resected sciatic ends. Transplant found of larger diameter than the sciatic. Well-developed central sciatic bulb noted. Sciatic and nerve transplant removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In a series of longitudinal sections through the distal end of the central stump and the central end of the transplant, it may be observed that nucleated syncytial strands of protoplasm extend for a short distance into the central end of the transplant; beyond this region the thickened neurolemma sheaths of the transplanted nerve fibers are found and seem to contain granular and globular detritus, and inwandered cells. There is observed a distinct small cell infiltration in this region. In the connective tissue to one side of the transplant, protoplasmic syncytial strands, grouped in small bundles, are observed in cross sections. These can not be definitely traced to the distal wound. The distal sciatic found completely degenerated.

Experiment No. 141.—Rabbit No. 86; only about one-half grown; 65 days. July 9, 1918, left sciatic exposed and resected 2.5 cm. A segment of equal length taken from the external popliteal bundle of the left sciatic of dog No. 26, cut June 7, 32 days previous, used as transplant. One central and distal waxed, fine silk thread suture placed; distal approximation good; central, good alignment but nerve ends about 2 mm. apart. Wound closed. September 12, found dead in the morning; much emaciated; slight neurotrophic changes left heel; posterior half of body paralyzed for past few days. On exposing the left sciatic, the transplant is found well in place; clearly demarked by its light yellow color; of good size and consistency and adherent to the underlying muscle. Quite distinct central sciatic bulb noted. Sciatic and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Not satisfactory silver differentiation attained.

Microscopic findings.—In sections, transplant clearly demarked by reason of its jet-black coloring. Neuraxes from the central nerve are seen to approach the central end of the transplant but do not penetrate it. Certain few neuraxes pass into the connective tissue to one side of the transplant, passing distally in the connective tissue. No new neuraxes are observed as having reached the distal wound. Distal sciatic degenerated.

Experiment No. 142.—Rabbit No. 80; full grown; 61 days. July 5, 1918, left sciatic exposed and resected 3 cm. A segment of equal length, taken from the right median of dog No. 26, cut June 7, 27 days previous, used as a transplant. One central and distal waxed, fine silk thread suture placed; good approximation. Adrenalin used to control oozing. Wound closed. September 4, found dead in the morning; seemed in good condition; slight neurotrophic ulcer left heel. On exposing the left sciatic, transplant is found well in place, of small diameter and of light yellow color; adherent to the underlying muscle. Distinct bulbous enlargement of the distal end of the central stump noted. The sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Fair silver differentiation attained.

Microscopic findings.—In longitudinal sections of the central wound region, downgrowing neuraxes from the central stump in small number are seen to pass distally to one side of the transplant and enter the connective tissue in which they may be traced not quite to the distal wound region. The region of the transplanted nerve fibers stained jet black; no structural details can be ascertained.

Experiment No. 143.—Rabbit No. 80a; full grown; 63 days. July 3, 1918, the right sciatic exposed and resected 3 cm. A segment of the right ulnar of dog No. 26, cut June 6, 27 days previous, used as transplant. One central and distal waxed, fine silk thread suture placed; good approximation. Adrenalin used to stop oozing; wound closed. September 4, rabbit found dead in the morning; seemed in good condition; neurotrophic ulcer right heel. On exposing the right sciatic, transplant is found well in place; clearly demarked

by its light yellow color; is of good size and consistency and is found adherent to the underlying muscle. Distinct central bulb noted. Sciatic and transplant removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In longitudinal sections through the central wound region, distinct central bulb evidenced structurally, from the distal end of which nucleated, syncytial, protoplasmic strands can be traced to the connective tissue found to one side of the transplant. In longitudinal sections of the transplant, the old neurolemma sheaths of certain of the transplanted nerve fibers seen, these appear thickened and present a wavy or zigzag course, containing a granular and globular detritus. Here and there inwandered leucocytes may be observed. The perineural sheaths present small cell infiltration. The distal nerve completely degenerated. No new nerve fibers found in the connective tissue surrounding the greater length of the transplant.

Experiment No. 144.—Rabbit No. 79; full grown; 84 days. June 19, 1918, the left sciatic exposed; internal popliteal freed and resected 3.1 cm. A segment of equal length, taken from the distal ulnar of dog No. 23, cut May 31, 19 days previous, used as transplant. One central and distal waxed, fine silk thread suture placed. Good approximation of nerve ends attained centrally; distally "fair." Wound closed. September 11, rabbit found dead in the morning; scarcely any neurotrophic changes in left hind foot. On exposing the left sciatic, external popliteal found free. The operated internal popliteal presents large central bulb. The transplant found well in place; is of light yellow color, of small diameter, especially in its middle portion; and found adherent to underlying muscle. The nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. The tissues removed in this experiment were lost in process of fixing and staining; no sections made.

Experiment No. 145.—Rabbit No. 79a; full grown; 84 days. June 19, 1918, right sciatic exposed; internal popliteal freed and resected 3 cm. A segment of equal length taken from the right median of dog No. 23, cut May 31, 19 days previous, used as transplant. One central and distal waxed, fine silk thread suture placed; good approximation. Wound closed. September 11. Rabbit found dead in the morning; very slight neurotrophic changes right hind foot. On exposing the right sciatic, operated internal popliteal is found to present large bulb along side of which external popliteal is found closely adherent. Transplant found well in place; clearly demarked by reason of light yellow color, and is adherent to underlying muscle. Nerve and transplant removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and light grün.

Microscopic findings.—In longitudinal sections of the central wound region, a large, distinct bulb is evidenced structurally, from the distal end of which nerve fibers, in part myelinated, pass to the connective tissue to one side of the transplant. In cross sections of the middle transplant region, the perineural sheaths found distinctly thickened and penetrated by inwandered cells. Within this sheath necrotic remains of the transplanted nerve fibers are found. To one side of the transplant, and outside of the perineural sheath, numerous small funiculi of nerves with certain fibers myelinated are to be observed. In cross and longitudinal sections taken at successive levels, these small bundles of nerves may be traced to the distal wound region, coursing in the connective tissue outside of the transplant; certain few are found to have reached the central end of the distal popliteal, here clearly recognized as small myelinated fibers.

Experiment No. 146.—Rabbit No. 81; full grown; 93 days. July 5, 1918, left sciatic exposed and resected 2.4 cm. A segment of equal length taken from the right median of dog No. 28, cut June 7, 28 days previous, used as a transplant. One central and distal waxed, fine silk thread suture placed. Good central approximation attained; distal suture does not include the external popliteal branch. Wound closed. October 6, killed. Rabbit found dying; much emaciated; severe neurotrophic ulcer left heel. On exposing, the left sciatic, transplant is found well in place; is of good size and light yellow color, and only moderately adherent to underlying muscle. Only slight spindle-shaped enlargement on central sciatic noted. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation attained.

Microscopic findings.—In series of longitudinal and cross sections taken at successive levels, the transplanted nerve segment is clearly demarked by reason of the jet-black color assumed in the silver stain. For a distance of approximately 2 mm., at the central and distal end of the transplant and in the peripheral part, adjacent to the perineural sheath the substance responsible for the peculiar jet-black silver reaction noted, has apparently disappeared, in that in these regions the transplant is colored a yellow brown. In longitudinal sections of the central wound region, certain neuraxes may be traced into central end of the transplant, to the region of the jet-black coloring; here they can no longer be differentiated. Other neuraxes pass to one side of the transplant, to the connective tissue. In cross sections of the transplant, mainly to one side, numerous small bundles of neuraxes are found in the connective tissue sheath. New neuraxes are observed in longitudinal sections of the distal wound region; certain of these appear to enter the distal wound through the transplant, others from the surrounding connective tissue. New neuraxes are found in good number in all of the funiculi of the distal popliteal in the region of the distal wound.

Experiment No. 147.—Rabbit No. 81a; full grown; 93 days. July 5, 1918, right sciatic exposed and resected 2.2 cm. A segment of equal length taken from the right ulnar of dog No. 28, cut June 7, 28 days previous, used as a transplant. One central and distal waxed, fine silk thread suture placed; good central and distal approximation. Wound closed. October 6, killed. Rabbit found dying; much emaciated; severe neurotrophic ulcer right heel. On exposing the right sciatic, transplant is found well in place; demarked by its light yellow color. At distal suture transplant appears to have pulled away slightly from distal sciatic stump. Transplant found only moderately adherent to underlying muscle. Quite distinct central bulb noted. Sciatic and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good silver differentiation attained.

Microscopic findings.—In series of cross and longitudinal sections, taken at successive levels, it may be observed that certain neuraxes coming from the central sciatic stump, enter the central end of the transplant and may be traced in it for a short distance. However, the majority of the central neuraxes are found to pass into the connective tissue to one side of the transplant and in cross sections of the transplant these are found in the form of small nerve funiculi outside of the perineural sheaths. Neuraxes can be traced through the distal wound into the distal popliteal stump. Certain of these appear to take exit from the distal end of the transplant; these can not be identified more centrally by reason of the jet-black coloring of the greater part of the transplant. The neuraxes found in the distal popliteal appear to be about equally distributed through the several funiculi and can be traced distally to the end of the series of sections approximately 3 cm. beyond the distal wound.

Experiment No. 148.—Rabbit No. 83; not quite full grown; 217 days. July 8, 1918, left sciatic exposed and resected 2.0 cm. A segment of equal length taken from the external popliteal of dog No. 25, the sciatic of which was cut June 7, 31 days previous, was used as a transplant. Dog No. 25 stopped breathing while under ether anesthesia, 45 minutes before the nerve was removed. One central and distal waxed, fine silk thread suture passed. Central suture not good; removed and another made; slight trauma of nerve ends; finally central and distal approximation good. Wound closed. February 10, 1919, killed. Rabbit in good condition; part of left hind foot missing; practically healed over; scarcely any evidence of long-standing neurotrophic ulcer left heel. On exposing the left sciatic, a large central bulb is found. The nerve in region of transplant adherent to underlying muscle. The distal sciatic presents the appearance of a normal nerve. After exposing the calf muscles and the leg flexors, and freeing nerve and transplant from the bed, on slowly cutting the sciatic with scissors, central to the transplant, good contraction of the calf and leg flexor muscles noted; the same on cutting nerve distal to the transplant. The calf muscles have nearly recovered size, but are of a pale red color. The sciatic and the transplant and portions of the calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Very good silver differentiation attained.

Microscopic findings.—In series of longitudinal and cross sections, taken at successive levels, it is observed that except for two small regions, of about 1.5 mm. in length, near the distal and central ends of the transplant, which are colored jet-black, the remainder of the nerve transplant is colored a light yellow-brown, as is the remainder of the nerve. In longitudinal sections of the central wound region numerous new neuraxes can be traced from

the distal end of the large central bulb into the transplant as well as into the connective tissue surrounding the transplant. In cross sections of the transplant in its middle region many small nerve funiculi, separated by endoneural fibrous tissue, are seen with the perineural sheath of the transplant. There are also found many small nerve bundles in the connective tissue outside of the perineural sheaths of the transplant. New neuraxes can be traced to and through the distal wound into the distal sciatic. In cross sections of the internal popliteal, taken at the lower level of the popliteal space, new neuraxes in large numbers are found in all of its several funiculi. In sections of the calf muscles new neuraxes in good relative numbers are found in the interfascicular muscle nerves and as single fibers on and between muscle fibers; motor endings and nerve endings in neuromuscular spindles are observed.

Experiment No. 149.—Rabbit No. 84; Belgian hare; not quite full grown; 240 days. July 9, 1918, right sciatic exposed and resected 2.2 cm. A segment of equal length, taken from the right ulnar of dog No. 26, cut June 7, 32 days previous, used as a transplant. One central and distal waxed, fine silk thread suture passed; good approximation. Diameter of the degenerated ulnar segment slightly greater than that of the resected sciatic. Adrenalin used to obtain dry field; wound closed. March 6, 1919, killed. Rabbit in good condition. No neurotrophic ulcer on right heel. On exposing the right sciatic a large central bulb is found on the central sciatic. Transplant is found of light yellow color, of good size and adherent to underlying muscles. The distal sciatic presents the appearance of a normal nerve. After exposing the calf muscles and freeing the sciatic from bed, on slowly cutting with scissors, sciatic central to the transplant, good contraction of calf muscles observed. Calf muscles are found to have nearly recovered size but are of pale red color. Sciatic and the transplant and portions of the calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Very good differential silver staining attained.

Microscopic findings.—In series of longitudinal and cross sections taken at successive levels the transplanted nerve segment is clearly demarked by reason of the jet-black coloring assumed by the transplanted nerve tissue. In longitudinal sections of the central wound region numerous central neuraxes can be traced to the periphery, mainly in the connective tissue outside of the transplant, as clearly seen in cross sections, taken about midway between central and distal wounds, in which two areas, situated at opposing sides of the transplant, there are found in the connective tissue numerous small bundles of nerve fibers situated outside of the perineural sheaths. Whether any neuraxes pass through the transplant can not be determined by reason of the jet-black coloring of the nerve bundle remains of the transplant. New neuraxes are observed in the distal wound and in the central end of the distal sciatic, in which they are found evenly distributed through the several funiculi. In sections of the calf muscle new neuraxes are found in the interfascicular nerve bundles, and here and there as single nerve fibers on and between muscle fibers.

As concerns degenerated auto-nerve transplant, Experiments No. 126 to No. 128, while only three in number, they may serve to show that a degenerated nerve can serve the purpose of an auto-nerve transplant though there is no indication that regeneration from the central stump through such a transplant takes place more readily than when an undegenerated auto-nerve transplant is used. Indeed the results attained are, on the whole, less satisfactory, if one may judge from the relatively few experiments. There are relatively more extrafunicular nerve fibers in the experiments in which a degenerated auto-nerve transplant was used than in the experiments in which cable-auto-nerve transplants were made.

In the series of five experiments (No. 129 to No. 133) in which degenerated homo-nerve transplants were used, the end results were on the whole very satisfactory and may compare very favorably with the end results in experiments in which a homogenous transplant was made, using a fresh nerve. Attention is especially called to Experiment No. 131, terminated 37 days after the operation. A nerve segment 3.4 cm. in length, taken from the distal portion of

a nerve cut 27 days previously, was used as a nerve bridge. In this experiment, numerous down-growing neuraxes are readily determined within the funiculi of the transplant; relatively few new nerve fibers are extra-funicular. In Experiment No. 132, a little over four months' duration, it was possible to trace new neuraxes to the foot interossei muscles, with good return of function. It is not likely that a degenerated nerve would be available for an auto-nerve transplant, in human surgery. It is quite within the bounds of possibility that a degenerated nerve from another individual, one to several months after injury, may be available for bridging a nerve defect, in which event it may be stated that experimental evidence warrants the use of a degenerated homo-nerve transplant. In nerve defect bridged by degenerated auto- and homo- nerve transplants, the down-growing central neuraxes make use of the patent or semipatent neurolemma sheath of the transplanted nerve fibers. There is no evidence that the transplanted syncytial nucleated strands stand in any definite relation to the down-growing neuraxes, since these strands undergo change, degenerate, after transplantation.

The experiments on degenerated hetero-nerve transplants (No. 134 to No. 149) did not substantiate the conjecture that the less specifically differentiated protoplasm of the "bandfasern", which may be regarded as in a measure representing a reversion to embryonic structure, offered a better avenue for the down growth of central neuraxes than would an undegenerated nerve transplant of the heterogenous origin. It may be noted that in the majority of the experiment protocols the notation is made that the transplant presents a light yellow color when the nerve is exposed some time after the operation. This enables ready demarkation of the transplant and is indicative of a necrobiotic change, involving not only the transplanted nerve fibers but the fibrous tissue sheaths of the nerve funiculi. The products of this necrobiotic change show a peculiar reaction to the pyridine-silver stain in that they assume a jet-black color, in which no tissue elements can be made out, and would mask any neuraxes in case they were present. This series of sixteen experiments need not be discussed seriatim; they range in time after operation from 7 days to 244 days. The results may be summarized by stating that a degenerated hetero-nerve transplant was found less serviceable than a nondegenerated nerve transplant of heterogenous origin owing to the fact that a degenerated hetero-transplant undergoes further change of necrobiotic nature, resulting in the formation of tissue detritus which appears to offer an effective block to the down-growing neuraxes. Whether this block is largely of a mechanical or to a large part of a chemical nature has not been determined. In all of the experiments under observation after the initial operation for more than 45 days, down-growing neuraxes could be traced into the central wound, but no distance into the transplant. Numerous neuraxes could be traced into the connective tissue surrounding the transplant, thus having extrafunicular position. Only in a few experiments were nerve-fibers in number found within the nerve funiculi of the transplant. Cross sections of the transplant region with good differential neuraxis staining are necessary to determine the relative position of the neuraxes, whether extrafunicular or intrafunicular, the latter indicating the efficacy of the transplant.

STORED HOMO-NERVE TRANSPLANTS

SERIES NO. 11

HOMO-NERVE TRANSPLANTS, STORED IN STERILE VASELINE

SERIES NO. 12

HOMO-NERVE TRANSPLANTS, STORED IN LIQUID PETROLATUM

SERIES NO. 13

HOMO-NERVE TRANSPLANTS, STORED IN 50 PER CENT ALCOHOL

In these series of stored homogenous transplants, totaling 67 experiments, we present a body of experimental observations, which we regard as of crucial importance in determining the true function of a nerve transplant. In none of these experiments can the transplant be regarded as being in the state of a living tissue.

The experiments under Series No. 11 were suggested to us through the publication of Dujarier and François,[76] who reported briefly a series of 20 cases in which homogenous nerve transplants, stored in vaseline, were used to bridge nerve defects. Dujarier and François recommended that nerves removed from amputated limbs under aseptic precautions be placed in sterile vaseline and kept at nearly 0° temperature. In their work as reported, nerves were kept in this way for 41 days. Before use the vaseline was warmed to melting, the nerve segment removed and rinsed in warmed serum, then sutured between the severed nerve ends. In the cases reported, healing took place by primary intention. Not enough time had elapsed from the time of operation to the time of the publication to make a report on the ultimate results.

At the time our observations were undertaken we were not aware of any experimental observations in which stored nerve transplants had been used. We followed as closely as possible the method as briefly outlined by Dujarier and François. The sciatics of large and full grown rabbits were removed under aseptic precautions, placed in large tube vials containing sterile melted vaseline, after which the tube vials were plugged with sterile cotton plugs. The tube vials were then placed in a small ice chest regulated to 3° C., in which they remained for periods varying in the several experiments from 9 days to 13 days. The nerves thus stored were used to bridge defects in the sciatics of rabbits caused by resection. Just before use the vial containing the nerve to be selected for the experiment was carefully warmed to an extent sufficient to melt the vaseline. The contained nerve segment was then removed and rinsed in warmed sterile serum, and a segment of proper length cut and sutured to the resected stumps of a rabbit's sciatic nerve. One fine, waxed silk suture was placed centrally and distally. The experimental operations are relatively simple. A nerve segment stored in vaseline is readily manipulated; the small amount of vaseline clinging to the nerve was disregarded at the operation, since it seemed to play no special part in the healing of the wound. The necessary warming of the vaseline, so that the nerve segment may be readily removed, with possibility of overheating the nerve segment, more particularly the washing of the nerve segment in serum, seemed to be objections to the

method as suggested by the French observers. It occurred to us that the same ends might be attained by using liquid petrolatum as a medium for storing nerve segments. This method of procedure was tested in Series No. 12, 40 experiments, in which homogenous nerve transplants stored in liquid petrolatum were used. In our experiments we used Squibb's liquid petrolatum, which is a clear, bland fluid. The required quantity was placed in large tube vials, corked with cotton plugs and autoclaved on successive days. After cooling to room temperature the tube vials were placed in a small ice chest regulated to 3°C. The sciatics of rabbits were removed under asepsis, placed in sterile cooled liquid petrolatum and stored in the ice chest until required for operation, for periods varying from 7 days to 39 days in the several experiments. Before an experiment the tube vial containing the nerve selected was taken from the ice chest and placed in the operating room, and when required the nerve segment was taken from the tube vial by means of forceps and, grasping the nerve segment at one end, was allowed to drain for a few minutes. The sutures were then placed at requisite distance and the nerve cut about 2 mm. distal to the suture and the nerve transplant sutured proximally and distally to the resected nerve ends. Nerve segments stored in liquid petrolatum have good consistency four to five weeks after removal from the animal and have nearly the same appearance as a normal nerve. The excess of liquid petrolatum drains off very readily; the thin coating clinging to the nerve transplant plays no part in the healing of the wound, so far as can be determined. It was our experience that storing of nerves in liquid petrolatum, as used by us, was much to be preferred to storing in vaseline as suggested by Dujarier and François.

Homogenous nerves transplants stored in 50 per cent alcohol were used in a further series of experiments (Series No. 13). The suggestion for this series of experiments came quite indirectly from observations published by Nageotte.[77] Nageotte had determined as a result of bilateral experimental operations on the sciatics of six dogs, in which on one side direct suture of the severed sciatic was made, while on the other side a 5 mm. long hetero-nerve transplant which had been stored in 50 per cent alcohol for some time was interposed between the severed ends of the cut sciatics and sutured in place, that better results could be reported in certain experiments for the side in which the short heterogenous nerve segment stored in alcohol was used. In Nageotte's experiments the heterogenous nerve was obtained from the slaughter house, placed in 50 per cent alcohol in sealed tubes, some of which were kept as long as 15 months. In our experiments the sciatics of full grown rabbits were removed under aseptic precautions and placed at once in 50 per cent alcohol, in sterile, wide-mouthed glass-stopped bottles, in which they were kept for periods varying from 7 days to 29 days. In the 50 per cent alcohol the nerve trunk becomes hardened, though not brittle, and of course can not be regarded as tissue retaining latent viability. Just before use as nerve transplants the nerve segments were taken from the alcohol and placed for 10 to 20 minutes in warmed, sterile, normal salt solution, in which, after a short stay, the nerve again becomes quite pliable. The nerve segments were taken from the normal salt solution, the sutures placed at requisite distance, the ends freshened by cutting with sharp scissors about 2 mm. beyond the suture lines, and

the operation completed by placing the alcoholized transplant between the resected sciatic stumps and sutured in place by making one central and one distal suture with fine silk thread waxed with sterile wax. The nerve segments stored in alcohol, after a short stay in the saline solution, are of good consistency and lend themselves readily to operative technique; sutures pass easily; end-to-end approximation is easily made. In our experimental work, nerve segments were stored in 50 per cent alcohol for about four weeks and at room temperature; they were kept in a dark cabinet. We have no observations indicating that nerve segments might not be stored in 50 per cent alcohol for a period of four months or more and then used as nerve transplants. This method of storing nerve transplants is so simple, the necessary precautions so easily met, that this method should commend itself as at least worthy of further experimental test.

Protocols of experiments under Series No. 11, No. 12, and No. 13, homo-nerve transplants stored in vaseline, liquid petrolatum, and 50 per cent alcohol follow:

PROTOCOLS

Experiment No. 150.—Rabbit No. 97; large; full grown; 66 days. October 4, 1918, left sciatic exposed, internal popliteal bundle freed and resected 3 cm. For nerve transplant there was used the internal popliteal bundle of another rabbit, removed nine days previous and stored in sterile vaseline at a temperature of 3° C. Just before use as transplant, the nerve segment washed for some minutes in sterile rabbit's serum. One central and one distal waxed fine silk suture placed. Good central and distal approximation of nerve ends attained. Dry field. Wound closed. December 8, rabbit found dead in the morning. Wound well healed. On exposing left sciatic no material increase of connective tissue about nerve and transplant noted. Transplant found well in place. Indistinct central bulbous enlargement; no material enlargement of central end of distal internal popliteal stump. Nerve and transplant not adherent to muscle bed. Central and distal popliteal and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining.

Microscopic findings.—Numerous down-growing neuraxes can be traced from the distal end of the central stump, through central wound to proximal end of transplant. Through this neuraxes can be traced in good number to and through distal wound to proximal end of the distal internal popliteal. In cross sections of the transplant neuraxes are found in small groups, separated by small areas containing vesicular cells and tissue detritus.

Experiment No. 151.—Rabbit No. 97a; large; full grown; 66 days. October 4, 1918, right sciatic exposed, internal popliteal bundle freed and resected 3 cm. A nerve segment of equal length, taken from the sciatic of another rabbit, stored in sterile vaseline nine days at 3° C. temperature, washed in sterile rabbit's serum several minutes, used as transplant. One central and one distal waxed, fine silk suture placed; good nerve-end approximation attained. Dry field. Wound closed. December 8, rabbit found dead in the morning. Wound well healed. Small neurotrophic ulcer right heel. Right sciatic exposed. Transplant found well in place. Only indistinct central bulbous enlargement. No material increase of connective tissue about nerve and transplant. Nerve and transplant removed and fixed in 5 per cent neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—Structurally considered, quite well defined central bulbous enlargement from the distal end of which many small nerve fibers nucleated, syncytial strands of protoplasm can be traced into the proximal end of the transplant and through this to the distal wound. Certain of the nerve fibers within the nerve transplants present thin myelin sheaths. The great majority of the new nerve fibers found within the transplant are arranged in the form of small bundles of narrow bands, here and there anastomosing, and separated by small areas or columns of vesicular cells and tissue detritus. The endoneural and perineural connective tissue not materially increased.

Experiment No. 152.—Rabbit No. 99; medium size; full grown; 89 days. October 7, 1918, left sciatic exposed, internal popliteal bundle freed and resected 3.0 cm. A nerve segment of equal length taken from the sciatic of another rabbit, stored 13 days in sterile vaseline, temperature 3° C., used as transplant. One central and one distal suture of waxed, fine silk thread placed. Good central and distal nerve-end approximation attained. Dry field. Wound closed. January 4, 1919, rabbit found dead 1 p. m.; living in the morning. Moderate emaciation; neurotrophic ulcer left heel. Wound well healed. Left sciatic exposed full length. External popliteal bundle found adherent along central wound. Transplant found well in place; small spindle-shaped central bulbous enlargement. Transplant found slightly adherent to underlying muscle; of light gray color and not quite as glistening as normal nerve. Distal wound not distinctly made out. Central and distal sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining.

Microscopic findings.—Good differential neuraxis staining attained. From the distal end of central bulbous enlargement which embraces central end of the transplant, numerous neuraxes are traced through the transplant, to and through the distal wound and into the proximal end of the distal popliteal stump in which for several centimeters well differentiated neuraxes are found in large numbers. In cross sections of the transplant, the new neuraxes present are found in the form of small funiculi separated by strands of endoneural connective tissue. Here and there small groups of vesicular cells, inclosing what appear to be lipoid globules, are noted. Distal internal popliteal well regenerated.

Experiment No. 153.—Rabbit No. 99a; medium size; full grown; 89 days. October 7, 1918, right sciatic exposed, internal popliteal bundle freed; resected 3.2 cm. A segment of equal length taken from the sciatic of another rabbit, stored in sterile vaseline, at a temperature of 3° C. for 13 days, used as transplant. One central and one distal waxed, fine silk thread suture placed. Good central and distal approximation attained. Dry field; wound closed. January 4, 1919, rabbit found dead 1 p. m.; nerve removed at once. Moderately emaciated; slight neurotrophic ulcer right heel. Wound well healed. Right sciatic exposed full length. Transplant found well in place; clearly demarked by presence of central and distal suture. Small spindle-shaped, central, bulbous enlargement. External popliteal bundle not adherent to underlying muscle. No appreciable distal enlargement. Central and distal sciatic and transplant removed and fixed in 5 per cent neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—Quite distinct central bulbous enlargement evidenced structurally, from the distal end of which many fine, myelinated nerve fibers and nucleated, protoplasmic, syncytial strands pass through the transplant to the distal wound. In cross sections of the transplant about 1 cm. distal to central wound, one large funiculus and two small funiculi of the transplant almost completely filled with new nerve fibers with only here and there small areas of tissue detritus and vesicular cells evident. The perineural sheaths of the transplanted nerve funiculi well maintained and only slightly thickened. Apparent regeneration through transplant; used histologic methods do not enable full determination of distal growth of new neuraxes.

Experiment No. 154.—Rabbit No. 98; large; full grown; Belgian hare; 96 days. October 5, 1918, left sciatic exposed, internal popliteal freed; resected 2.5 cm. A segment of equal length, taken from the sciatic of another rabbit, stored in sterile vaseline, temperature 3° C., 11 days, used as nerve transplant. One central and one distal suture of waxed, fine silk thread placed. Only fair central and distal nerve-end approximation attained. Dry field; wound closed. January 9, 1919, killed. Rabbit much emaciated; "fungus" ears; severe neurotrophic ulcer left heel; on the whole quite active. Wound well healed. Left sciatic exposed full length. External popliteal bundle found quite free. Large spindle-shaped central bulbous enlargement noted on central internal popliteal stump; slight enlargement of the central end of distal stump. Transplant well in place; light gray color, not adherent to underlying muscle. Unoperated external popliteal bundle resected and removed. Calf muscles fully exposed; operated internal popliteal and transplant completely freed from bed. On slowly cutting with scissors sciatic central to transplant doubtful, feeble contractions of calf muscles. On cutting internal popliteal lower level of popliteal space, feeble contraction of calf muscles; uncertain. Central and distal sciatic and trans-

plant and pieces of calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining.

Microscopic findings.—Only fair silver differentiation attained; calf muscles silver staining good. Distinct central bulbous enlargement evidenced structurally from the distal end of which numerous new neuraxes pass through the transplant to the distal popliteal nerve. In sections of the calf muscles, numerous new neuraxes found in the larger muscular branches, relatively fewer in the smaller interfasicular branches and here and there single nerve fibers seem to pass to muscle fibers. Muscle fibers of small diameter, but show distinct cross striations. Muscle capillaries very numerous and very tortuous. Regeneration of distal popliteal to muscular branches of the calf muscle, beginning recovery of motor function of these muscles.

Experiment No. 155.—Rabbit No. 98a; large; full grown; Belgian hare; 96 days. October 5, 1918, right sciatic exposed; internal popliteal bundle freed; resection 2.5 cm. A segment of equal length taken from the sciatic of another rabbit, stored 11 days in sterile vaseline at 3° C., used as transplant. One central and one distal waxed, fine silk thread suture placed; quite good approximation of nerve ends attained. Dry field; wound closed. January 9, 1919, killed. Rabbit much emaciated; "fungus" ears; severe neurotrophic ulcer right heel. Wound well healed. Right sciatic exposed full length. External popliteal bundle quite free; resected and removed. Operated internal popliteal bundle shows the transplant well in place, of good size and light gray color. Large, spindle-shaped central bulbous enlargement noted. After fully exposing the calf muscles and freeing the internal popliteal bundle from bed, on slowly cutting with scissors, the nerve central to transplant, no distinct twitching of calf muscles; the same on cutting distal to transplant. Operated nerve with transplant and portions of calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation fair; calf muscles good.

Microscopic findings.—Large central bulb evidenced structurally, from the distal end of which numerous new neuraxes may be traced through the transplant to the distal segment. In sections of calf muscles, numerous new neuraxes noted in the muscular nerves; a few of these may be traced between muscle fibers. Distal regeneration to and into the calf muscles.

Experiment No. 156.—Rabbit No. 100; large; full grown; 155 days. October 8, 1918, left sciatic exposed; internal popliteal bundle freed and resected 3.0 cm. A segment of equal length taken from the sciatic of another rabbit, stored 12 days in sterile vaseline, temperature 3° C., used as transplant. One central and one distal waxed, fine silk thread suture placed. Good central and distal nerve-end approximation attained. Dry field; wound closed. March 12, 1919, killed. Rabbit in very good condition; neurotrophic ulcer healed; left foot appears normal; walks well, except now and then toe-drop; spreads toes of left foot on holding up by ears. Left sciatic exposed the whole length; external popliteal bundle free; resected and removed. Internal popliteal in operated region has the appearance of a normal nerve; scarcely any evidence of central bulb; no enlargement at the distal wound. Transplant not adherent; no material increase of connective tissue surrounding operated nerve. After exposing the calf muscles and removing skin to heel and completely freeing the operated nerve, on slowly cutting the nerve central to the transplant, vigorous and repeated contraction of calf muscles and apparently foot muscles; the same on cutting nerve distal to transplant. Operated nerve removed and fixed in ammoniated alcohol for pyridine-silver staining; portions of calf muscles removed for gold chloride method of staining nerve terminations. Differential silver staining only of a portion of the nerve good.

Microscopic findings.—Transplant well united to resected nerve ends; scarcely any evidence of central and distal wounds; these demarked by retained silk sutures. New neuraxes in great numbers pass through transplant to the distal nerve. For the transplanted nerve segment, the perineural sheaths of the funiculi well maintained. Within the funiculi the new neuraxes arranged in small groups, separated by endoneural connective tissue, much more extensive than in normal nerve. An attempt was made to endeavor to stain the motor nerve ending in gold chloride. This attempt not successful. In certain of the large muscular nerve bundles the neuraxes beautifully differentiated even into the smaller branches, but motor ending not differentiated. It seems clear that this is due to faults in the method,

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perhaps impurity of chemical used. Very complete regeneration of distal nerve through the transplanted nerve segment.

Experiment No. 157.—Rabbit No. 100a; full grown; 155 days. October 8, 1918, right sciatic exposed; internal popliteal bundle freed and resected 3.0 cm. A segment of equal length taken from the sciatic of another rabbit, stored 12 days in sterile vaseline at 3° C. used as transplant. One central and distal suture of waxed, fine silk thread placed. Central suture nerve-end approximation good; distal not good. Slight manipulation caused this distal suture to give way. Another suture placed; slight traumatism of nerve end, otherwise approximation good. Fairly dry field; wound closed. March 12, 1919, killed. Rabbit very good condition; small neurotrophic ulcer right heel. Right foot otherwise normal; spreads toes on holding up by ears. Left sciatic exposed the full length. External popliteal free full length; resected; removed. Operated internal popliteal presents scarcely any evidence of central bulb; transplant well in place; good color; good size. After exposing fully the calf muscles and freeing internal popliteal, on slowly cutting nerve central to transplant, good contraction of calf muscles. Operated nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining; calf muscles removed for gold chloride staining. Silver differentiation of neuraxes fairly good.

Microscopic findings.—Transplant well united to resected nerve ends; only slight structural evidence of central bulbous enlargement. New neuraxes in large numbers traced through transplant to distal nerve. In the transplant these new neuraxes arranged in the form of small bundles separated by endoneural connective tissue. An attempt made to stain the motor endings in gold chloride not successful. Numerous neuraxes found in the larger and smaller nerve branches clearly differentiated, but not motor endings. The muscle fibers present the size and structure of normal muscle fibers. Very good regeneraton of distal nerve through the transplant.

Experiment No. 158.—Rabbit No. 108; large; full grown; 1 hour. December 17, 1918, left sciatic exposed; internal popliteal bundle freed; resected 3.0 cm. A segment of equal length taken from the sciatic of another rabbit, stored seven days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal waxed fine silk thread suture placed; good approximation attained. Wound closed. As soon as wound was closed rabbit stopped breathing and could not be revived. Wound was reopened and the sciatic and transplant removed, about one hour after the operation was completed, and fixed in ammoniated alcohol for pyridine-silver staining. Experiment is recorded, since it enabled examining histologically a nerve stored in liquid petrolatum immediately after it had been placed in the wound. Good differential silver staining.

Microscopic findings.—The appearance presented in cross and longitudinal sections of the transplant, embedded in living tissue only about one hour, may be regarded as essentially the same as that of a nerve stored in liquid petrolatum for a period and examined before transplantation. The sections obtained present in essentials the appearance presented by a fresh nerve fixed and stained after the pyridine-silver method. Especially is this true of cross sections. In longitudinal sections the neuraxes are seen as unsegmented strands of regular contour. The "Golgi-funnels" of the myelin, are distinctly evident though not quite so regular as in a fresh, normal nerve. The sheath cells were not differentiated.

Experiment No. 159.—Rabbit No. 108a; large; full grown; 1 hour. December 17, 1918, right sciatic exposed; internal popliteal freed; resected 3.0 cm. A segment of equal length removed from the sciatic of another rabbit, stored seven days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal waxed, fine silk thread suture placed. Good approximation attained. Wound closed. Rabbit stopped breathing while this operation was being completed and could not be revived. About one hour after the operation was begun, sciatic and the transplant removed and fixed in neutral formalin. Stained in iron-hematoxylin and picro-fuchsin and in safranine and licht grün.

Microscopic findings.—Cross and longitudinal sections of the transplant present appearances which resemble very closely that of a normal nerve fixed and stained as above indicated. In cross sections of the nerve transplant, the nerve fibers have not so compact an arrangement as in a normal nerve, though the fibers themselves have the appearance of normal nerve fibers. In longitudinal sections, the fibers present a regular contour, the neuraxes even

borders and are not shrunken; the neurokeratin net of the myelin, very regular and distinct. The sheath nuclei present normal form and size and reaction to stains.

Experiment No. 160.—Rabbit No. 105; full grown; Belgian hare; 2 days. November 8, 1918, left sciatic exposed; internal popliteal freed; resected 3.0 cm. A segment of equal length taken from the sciatic of another rabbit, stored 38 days in liquid petrolatum at 3° C., used as transplant. One central and one distal waxed, fine silk thread suture placed; good approximation attained. Wound closed. November 10, rabbit found dead in the morning. Wound clean; healing. Left sciatic exposed. Quite a large blood clot over nerve region of central wound. Nerve sutures in place. Ends of transplant and resected nerve ends not as yet united. Sciatic and transplant removed and fixed in neutral formalin. Stained in iron-hematoxylin, picro-fuchsin and safranine and licht grün.

Microscopic findings.—In both cross and longitudinal sections of the transplant, it may be observed that the transplanted nerve fibers retain their form and structure very well. The neuraxes are not segmented, the myelin sheaths show clearly a neurokeratin net, the sheath nuclei distinctly evident and stain readily, though of more uniform color than normal nuclei.

Experiment No. 161.—Rabbit No. 105a; full grown; Belgian hare; 2 days. November 8, 1918, right sciatic exposed; internal popliteal freed; resected 2.8 cm. A segment of equal length taken from the sciatic of another rabbit, stored in liquid petrolatum 38 days at 3° C., used as transplant. One central and one distal waxed, fine silk thread suture placed; good approximation. Wound closed. November 10, rabbit found dead in the morning. Wound clean; healing. Right sciatic exposed. Nerve transplant found well in place, not adherent to resected nerve ends and surrounding tissues. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining.

Microscopic findings.—Silver staining not successful; no differentiation of neuraxes in normal central stump. In the transplanted nerve the neurolemma sheaths differentiated. These appear slightly thickened; other structures not clearly differentiated.

Experiment No. 162.—Rabbit No. 106; full grown; 2 days. November 8, 1918, left sciatic exposed; internal popliteal freed; resected 2.5 cm. A segment of equal length taken from the sciatic of another rabbit, stored 38 days in liquid petrolatum at 3° C., used as transplant. Central and distal waxed, fine silk suture placed; good approximation. Wound closed. November 10, rabbit found dead in the morning. Sciatic and transplant removed and fixed in neutral formalin. Stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—Nerve fibers of the transplant very well preserved. No segmentation of the neuraxes of nerve fibers of the transplant noted. In many of the nerve fibers neurokeratin net of the myelin well stained, in others no longer evident. Sheath nuclei evident and well stained. Transplant loosely adherent to resected nerve ends. Centrally very little inwandering of leucocytes into the nerve transplant. Centrally and distally, hemorrhage into resected nerve ends. As yet no evidence of degeneration of the nerve fibers of the distal nerves.

Experiment No. 163.—Rabbit No. 106a; full grown; 2 days. November 8, 1918, right sciatic exposed; internal popliteal bundle freed; resected 2.5 cm. A segment of equal length taken from the sciatic of another rabbit, stored in liquid petrolatum 38 days at 3° C., used as transplant. One central and one distal waxed, fine silk thread suture placed; approximation good. Wound closed. November 10, rabbit found dead in the morning. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining.

Microscopic findings.—In cross sections of the nerve transplant, neuraxes differentially stained, though of paler color than in normal nerve; neurolemma sheaths stand out clearly and appear as if slightly thickened.

Experiment No. 164.—Rabbit No. 102; full grown; 4 days. November 4, 1918, left sciatic exposed; internal popliteal freed; resected 2.8 cm. A segment of equal length taken from the sciatic of another rabbit, stored in sterile petrolatum 35 days at 3°C., used as transplant. One central and one distal waxed, fine silk thread suture placed; good approximation. Wound closed. November 8, rabbit found dead in the morning. Superficial wound clean and dry; nearly healed. Left sciatic exposed. Transplant found well in place; sutures show

clearly. Transplant presents a light yellow-white color; not adherent to underlying muscle; loosely united to the resected nerve ends. Resected nerve ends appear congested. Sciatic and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Fair differential silver staining attained.

Microscopic findings.—In the transplanted nerve segment, both in cross and longitudinal sections, the neuraxes still evident, though staining very lightly, the majority not as yet fragmented; certain ones showing a granular change. Neurolemma sheaths well maintained, and appear slightly thickened. Neurokeratin net and Golgi funnels not clearly seen. In the central end of the transplant are seen a number of distended capillaries, grown into the transplant from the central nerve stump. These capillaries have only endothelial walls and are distended with blood cells and have grown toward the periphery between the nerve fibers of the transplant. The distal segment presents evidence of early stages of nerve degeneration.

Experiment No. 165.—Rabbit No. 102a; full grown; 4 days. November 4, 1918, right sciatic exposed; internal popliteal freed; resected 2.8 cm. A segment of equal length taken from the sciatic of another rabbit and stored in sterile liquid petrolatum 35 days at 3° C., used as transplant. One central and one distal waxed, fine silk thread suture placed; good approximation. Wound closed. November 8, rabbit found dead in the morning. Superficial wound found clean and dry and nearly healed. Right sciatic exposed. Transplant found well in place, of yellow-white color, nonadherent and loosely united to the resected nerve ends. Sciatic and transplant removed and fixed in neutral formalin. Stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In cross and longitudinal sections of the nerve transplant, the nerve fibers found to be very well maintained; neuraxes present and not fragmented. The neurokeratin net of myelin only here and there clearly brought out. The neurolemma sheaths not collapsed, and of regular contour. Neuraxes of the transplant seen best preserved in the immediate vicinity of the central and distal wounds; in these regions stain much more clearly than in the body of the transplant. Nerves of the distal segment show beginning stages of degeneration evidenced in fragmentation of the myelin.

Experiment No. 166.—Rabbit No. 117; full grown; 4 days. December 27, 1918, left sciatic exposed; internal popliteal freed; resected 3.1 cm. A segment of equal length taken from the sciatic of another rabbit, stored 13 days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal waxed, fine silk thread suture placed; good approximation. Wound closed. December 31, rabbit found dead in the morning. Superficial wound healed. On removing skin over operated field, bloody exudate in subcutaneous tissue about wound and in deeper wound about transplant noted. Transplant found well in place; not adherent to surrounding tissue, loosely united to resected nerve ends. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. In part very good silver differentiation attained.

Microscopic findings.—In longitudinal sections of the transplanted nerve segment, it may be observed that the neuraxes are undergoing changes; many appear fragmented into longer or shorter segments, of distinctly granular structure. The neurolemma sheaths well maintained, though in many fibers showing alternate slight distensions or constrictions. Capillaries coming from the central nerve stump extend nearly the whole length of the nerve transplant. Distal nerve shows early stages of degeneration.

Experiment No. 167.—Rabbit No. 117a; full grown; 4 days. December 27, 1918, right sciatic exposed; internal popliteal freed; resected 3.2 cm. A segment of equal length taken from the sciatic of another rabbit, stored 13 days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal waxed, fine silk suture placed; good approximation. Diameter of transplant smaller than that of the resected nerve. Wound closed. December 31, rabbit found dead in the morning. Superficial wound found healed. Right sciatic exposed. Transplant found well in place; but surrounded by a blood clot. Sciatic and transplant removed and fixed in neutral formalin. Stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In cross and longitudinal sections of the transplanted nerve segment, it is observed that the neuraxes are beginning to show a fragmentation. These fragments of neuraxes are found inclosed in myelin segments in which the neurokeratin net

is still evident, and are found within neurolemma sheaths. No evidence of proliferation of the sheath cells of the transplanted nerves ascertained. Capillaries containing blood cells, and extravasated blood cells found between the nerve fibers of the transplant. In the distal segment, beginning fragmentation of neuraxes and myelin; hypertrophy of the sheath cells noted; here and there these fill the neurolemma sheaths; as yet no distinct proliferation of the sheath cells observed.

Experiment No. 168.—Rabbit No. 127; full grown; 5 days. March 4, 1919, left sciatic exposed; internal popliteal freed; resected 3.1 cm. A segment of equal length taken from the sciatic of another rabbit, stored twenty-one days in liquid petrolatum at 3° C., used as transplant. One central and one distal waxed, fine silk thread suture placed. Good central approximation attained; distal only fair. Wound closed. March 9, rabbit found dead in the morning. Transplant found well in place, easily demarked by sutures; united to resected nerve ends; not adherent to surrounding tissue. Sciatic and transplant removed and fixed in neutral formalin. Stained in safranine and licht grün.

Microscopic findings.—In longitudinal sections of the transplanted nerve segments fragmentation of neuraxes noted; these fragments have a granular structure. The neurolemma sheaths well maintained but of irregular contour. Long, rod-shaped nuclei are found in relation with the nerve fibers. It is difficult to determine whether these nuclei are within the neurolemma sheaths or situated on their outer surface. The appearances presented in cross sections of the transplant enable the determination that the majority of these nuclei are situated between the nerve fibers, thus outside of the neurolemma sheaths and of connective tissue derivation. Numerous wandering leucocytes found between the nerve fibers of the transplant in the immediate vicinity of both the central and distal wounds.

Experiment No. 169.—Rabbit No. 112; full grown; 6 days. December 21, 1918, left sciatic exposed; internal popliteal freed; resected 2.3 cm. A segment of equal length taken from the sciatic of another rabbit, stored nine days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal waxed, fine silk thread suture placed. Central suture not good; removed and resutured; approximation fair; distal good. Wound closed. December 27, rabbit found dead in the morning. Superficial wound healed; deep wound, blood clot about transplant. Central suture not good. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. In part good silver differentiation attained.

Microscopic findings.—New neuraxes budding from central stump; neuraxes can be traced into the central wound; these not as yet numerous. In the transplant, the neuraxes of the transplanted nerves found for the greater part in the form of short segments having wavy or spiral course. Neurolemma sheaths well maintained and of regular contour. Beginning stages of nerve degeneration noted in the distal segment.

Experiment No. 170.—Rabbit No. 112a; full grown; 6 days. December 21, 1918, right sciatic exposed; internal popliteal freed; resected 2.6 cm. A segment of equal length taken from the sciatic of another rabbit, stored nine days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal waxed, fine silk suture placed; good approximation; small hematoma under fascial tissue in popliteal space. Wound closed. December 27, rabbit found dead in the morning. Wound well healed. On exposing sciatic, transplant found well in place and united to the resected nerve ends. Sciatic and transplant removed and fixed in neutral formalin. Stained in iron-hematoxylin and picro-fuchsin, safranine and licht grün.

Microscopic findings.—In longitudinal sections of the transplanted nerve segment, the neuraxes of the transplanted nerves appear fragmented in short segments. These segments are here and there swollen and globular and for the most part inclosed in myelin in which a neurokeratin net is still evident. The neurolemma sheaths are well maintained. Within these sheaths are found the myelin segments and neuraxes segments shrunken in longitudinal direction, leaving spaces in which a granular precipitate is seen. Sheath cells not evident. Capillaries course between the nerve fibers of the transplant. Distal segment found degenerating.

Experiment No. 171.—Rabbit No. 109; full grown; Belgian hare; 12 days. December 18, 1918, left sciatic exposed and internal popliteal bundle freed; resected 2.4 cm. A segment

of equal length taken from the sciatic of another rabbit, stored eight days in liquid petrolatum at 3° C., used as transplant. One central and one distal suture placed; approximation, both central and distal, only fair. Wound closed. December 30, rabbit found dead in the morning. Wound well healed. Left sciatic exposed. Transplant found well in place and adherent to surrounding tissue which is discolored; bloody exudate. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation good; nuclei in part stained.

Microscopic findings.—Early stages of central bulbous enlargement evidenced structurally. Central end of transplant well united to central stump; fibrous and cellular tissue constitutes central wound. Down-growing neuraxes from the central stump noted in passage through central wound. Certain of these have reached the central end of the transplant in which they have passed distally to the extent of approximately 2 mm. In the greater part of the nerve transplant no new neuraxes seen. Many remnants of old neuraxes evident,

FIG. 228.—Cross section of homo-nerve transplant, stored in liquid petrolatum, at 3° C., 8 days before use as transplant, Experiment No. 171, 12 days after operation; pyridine-silver preparation. Note the distinct funicular structure of the nerve transplanted and the want of fibroblastic differentiation about the nerve transplant as a whole

either deeply stained fragments or of lighter color and granular structure. Sheath cells here and there evident. Myelin not clearly differentiated. In the distal nerve segment, nerve fibers in degeneration, sheath cells proliferated; many nucleated, syncytial protoplasmic bands; myelin ovoids and fragments of old neuraxes present.

EXPERIMENT No. 172.—Rabbit No. 109a; full grown; Belgian hare; 12 days. December 18, 1918, right sciatic exposed; internal popliteal bundle freed; resected 2.5 cm. A segment of equal length taken from the sciatic of another rabbit, stored eight days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal waxed, fine silk-thread suture placed; good approximation attained. Dry wound; wound closed. December 30, rabbit found dead in the morning. Superficial wound well healed. On removing skin over operated area, small area of focal infection noted; deep wound healed, no evidence of infection. Transplant found well in place; only moderately adherent to surrounding tissue. The sciatic and transplant removed and fixed in neutral formalin. Stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—Transplant firmly united to central and distal ends of resected nerve by means of cellular fibrous tissue layer. Distinct central bulbous enlargement and slight distal enlargement. In longitudinal sections of the transplant, taken from its middle third, neurolemma sheaths of the transplanted nerve fibers well maintained and appear as slightly thickened. Myelin observed in the form of smaller and larger globules or segments, the larger of which inclose fragments of old neuraxes. Fibrous sheaths of the transplant invaded by wandering cells. Within the transplant many long nuclei with rounded ends. The majority of these appear to be situated between the nerve fibers; others appear to be within the neurolemma sheaths; their histogenesis uncertain. Distal segment of nerve found in degeneration.

Experiment No. 173.—Rabbit No. 107; large; full grown; Belgian hare; 23 days. November 10, 1918, left sciatic exposed; internal popliteal bundle freed; resected 3.2 cm. A segment of equal length taken from the sciatic of another rabbit, stored thirty-nine days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal waxed, fine silk-thread suture placed; very good approximation attained. Dry field; wound closed. December 2, rabbit found dead in the morning. Wound well healed. Left sciatic exposed full length. External popliteal free and runs normal course. The nerve transplant found well in place. Material increase of connective tissue about the central and distal wounds. Transplant of yellow-white color and appears as if slightly congested. Transplant firmly united to resected nerve ends. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation centrally very good, distally not uniform.

Microscopic findings.—A distinct central bulb evidenced structurally. From the distal end of this bulb numerous neuraxes pass to and through the central wound into central end of transplant, in which they may be traced to the neighborhood of the distal wound. The distal wound appears not to have been penetrated by down-growing neuraxes nor are any new neuraxes to be found in the central end of the distal nerve. In cross sections of the nerve transplant, about 1 cm. distal to the central wound, new neuraxes found in all parts of the transplanted nerve. In many regions small groups of new neuraxes appear to pass distally within one old neurolomma sheath; certain neuraxes observed between or outside of neurolemma sheaths. Perineural sheaths of the transplanted nerve funiculi not materially thickened.

Experiment No. 174.—Rabbit No. 107a; large, full grown; Belgian hare; 23 days. November 9, 1918, right sciatic exposed; internal popliteal freed; resected 3.2 cm. A segment of equal length taken from the sciatic of another rabbit, stored 39 days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal waxed, fine silk-thread suture placed; good approximation; dry field; wound closed. December 2, rabbit found dead in the morning. Wound healed. Cold abscess over right gluteal region; not related to wound. The right sciatic exposed full length. Transplant found well in place and firmly united to the resected nerve ends; quite adherent to surrounding tissue; of yellow-white color. Quite well developed central bulbous enlargement. Sciatic and transplant removed and fixed in neutral formalin. Stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—Fibrocellular central wound into which extend nucleated protoplasmic bands. In longitudinal sections of the transplant, from about its middle third, myelin of the transplanted nerve segments in the form of larger and smaller globules, certain of which are found to contain fragments of the old neuraxes. Numerous, relatively large round or oval nuclei found within the old neurolemma sheaths. Histogenesis of these is uncertain. The neurolemma sheaths well maintained and appear slightly thickened. Distal nerve not sectioned.

Experiment No. 175.—Rabbit No. 133; large; old; Belgain hare; 82 days. March 15, 1919, left sciatic exposed; internal popliteal freed; resected 3 cm. A segment of equal length taken from the sciatic of another rabbit, stored seven days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal waxed, fine silk-thread suture placed; good approximation attained. Wound not quite dry; wound closed. June 5, killed. For several days had not eaten well; much emaciated; moribund when killed. Severe neuro-

trophic ulcer left heel. Wound well healed. Left sciatic exposed full length. External popliteal found free from operated internal popliteal. The transplant found well in place; no material increase of connective tissue about transplant. Large, spindle-shaped central bulbous enlargement. Distal suture clearly seen. Calf muscles exposed; these are atrophic and of pale-red color; appearance of degenerated muscles. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation not uniform throughout.

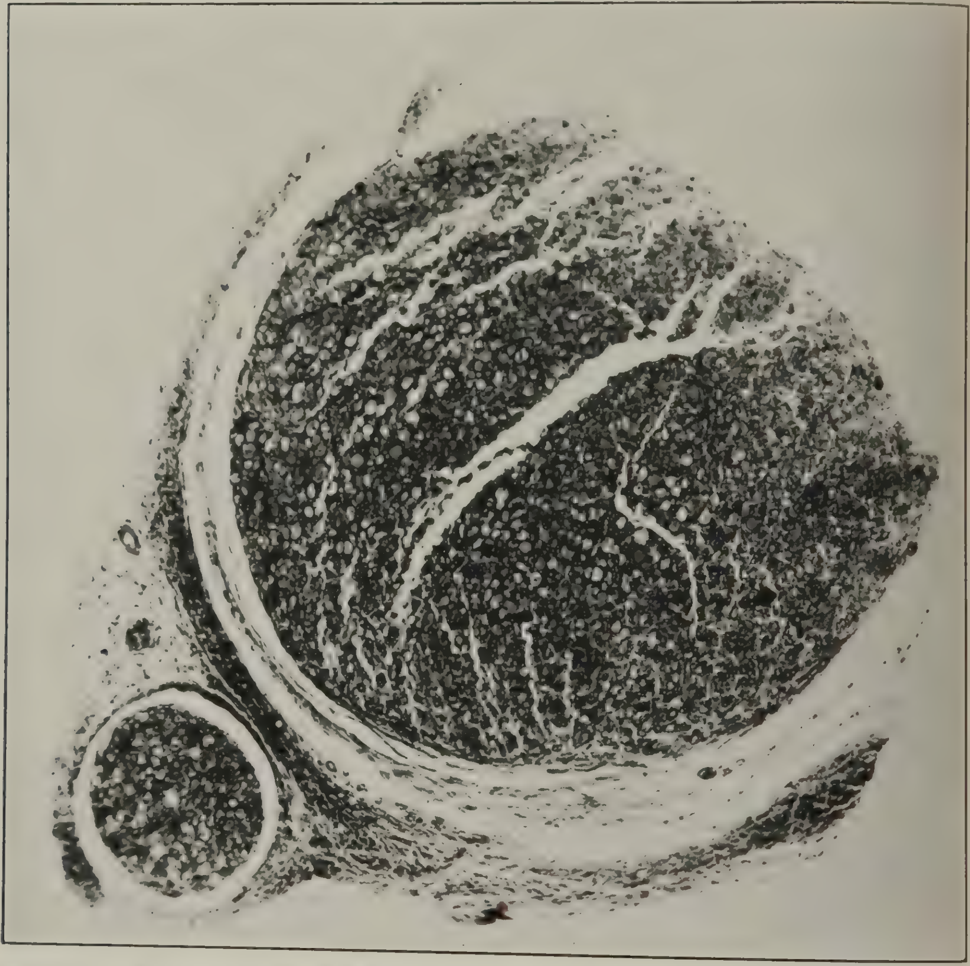

Fig. 229.—Cross section of homo-nerve transplant, stored in liquid petrolatum at 3° C. for 39 days before use, Experiment No. 174, removed 23 days after operation; pyridine-silver preparation. Attention is called to the distinct funicular structure presented by this nerve and the small amount of fibrous tissue development surrounding the nerve

Microscopic findings:—New down-growing neuraxes can be traced from distal end of central bulbous enlargement to and into transplant and in this to and through the distal wound into the central end of the distal nerve segment. Within the transplant these new neuraxes have a very regular, longitudinal course and appear to pass distally within and outside of old neurolemma sheaths. Areas of degenerated or fragmented myelin of the transplanted nerves observed, between which and around which the down-growing neuraxes pass.

Experiment No. 176.—Rabbit No. 131; large; full grown; 82 days. March 12, 1919, left sciatic exposed; internal popliteal bundle freed; resected 2.9 cm. A segment of equal

length taken from the sciatic of another rabbit, stored in sterile liquid petrolatum 23 days at 3° C., used as transplant. One central and one distal suture of waxed, fine silk thread placed. Central suture pulled out; resutured, a little traumatism to central resected stump resulted; central approximation only fair; distal good. Wound closed. June 2, rabbit found dead in the morning. Slightly emaciated; neurotrophic ulcer left heel. Wound well healed. Left sciatic exposed full length. No material increase of connective tissue about nerve. External adherent to side of operated internal popliteal. Transplant well in place; of light reddish-brown color; not adherent to surrounding tissue. Sciatic and transplant

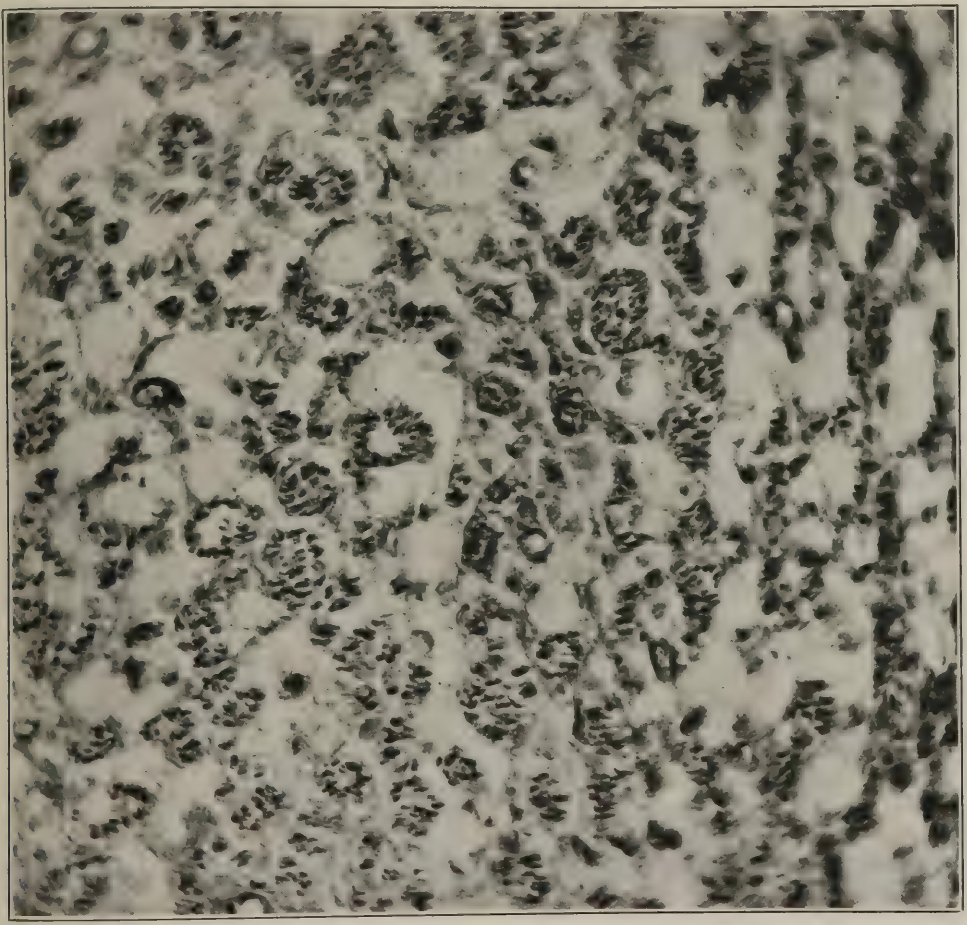

Fig. 230.—Cross section of homo-nerve transplant stored in liquid petrolatum 39 days at 3° C. before use; Experiment No. 174. Experiment terminated 23 days after operation. Higher magnification of portion of the larger funiculus shown in Figure 229. Note the new neuraxes seen in cross section as fine black dots, many of which are found within neurolemma sheaths of the transplanted nerve fibers

removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation only partially successful; tissue not well embedded and difficult to cut; sections torn.

Microscopic findings.—Numerous new neuraxes can be traced from the central stump to and through the distal wound. The differential staining of the distal nerve not successful, thus can not clearly determine whether new neuraxes have reached the distal popliteal.

Experiment No. 177.—Rabbit No. 129; full grown; 112 days. March 7, 1919, left sciatic exposed; internal popliteal freed; resected 2.9 cm. A segment of equal length taken from the sciatic of another rabbit, stored in sterile liquid petrolatum 17 days at 3° C., used as

transplant. One central and one distal waxed, fine silk thread suture placed; good approximation. Wound closed. June 27, killed. Rabbit much emaciated; not well; severe neurotrophic ulcer left heel. Wound well healed. Left sciatic exposed full length. External popliteal adherent to operated internal popliteal; both bundles surrounded by a dense fibrous tissue sheath and adherent to underlying muscle. Transplant found well in place and of good size. Calf muscles fully exposed; are atrophic and of pale red color. Sciatic completely freed from bed. On slowly cutting with scissors, sciatic central to transplant, vigorous contraction of the foot flexors supplied by the external popliteal, unoperated, but only very feeble and doubtful twitching of calf muscles supplied by operated internal popliteal. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Fair differential silver staining throughout the series of sections attained.

Microscopic findings.—Large, spindle-shaped central bulbous enlargement evidenced structurally, from the distal end of which new, down-growing neuraxes may be traced through the transplant, to and through the distal wound and in good numbers into the central end of the distal popliteal, in which they may be traced to the lower level of the popliteal space. Unfortunately the calf muscles were not removed for microscopic examination; it is thus not possible to report on the presence or absence of new neuraxes in the calf muscles. Microscopic findings indicate partial regeneration of the distal nerve segment through the nerve transplant.

Experiment No. 178.—Rabbit No. 104; full grown; 117 days. November 7, 1918, left sciatic exposed; internal popliteal freed; resected 3 cm. A segment of equal length taken from the sciatic of another rabbit, stored 38 days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal waxed, fine silk thread suture placed; good central approximation, distal fair. Wound closed. March 4, 1919, killed. Rabbit found nearly moribund; "fungus" ears; eyes infected; much emaciated; wound well healed; neurotrophic ulcer left heel. On exposing the left sciatic, transplant found well in place, of small diameter, adherent to underlying muscle. Large, spindle-shaped central bulb. Calf muscles fully exposed; these appear atrophic and of pale red color and do not respond distinctly on cutting the sciatic central to the transplant. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Not complete and uniform silver differentiation.

Microscopic findings.—Sections show sufficient silver differentiation of neuraxes to determine the observation that neuraxes growing from the central bulb enter the transplant and pass through this to and through distal wound into the central end of distal popliteal, in which region the staining is better; here numerous new neuraxes are differentiated. Regeneration through transplant of central end of distal popliteal.

Experiment No. 179.—Rabbit No. 104a; full grown; 117 days. November 7, 1918, right sciatic exposed; internal popliteal freed; resected 2.5 cm. A segment of equal length taken from the sciatic of another rabbit, stored 38 days in sterile liquid petrolatum at 3° C., used as transplant. One central and distal waxed, fine silk thread suture placed; good approximation. Wound closed. March 4, 1919, killed. Rabbit found nearly moribund; only slight neurotrophic ulcer right heel. On exposing right sciatic, transplant is found well in place, of good size and only slightly adherent to the underlying muscle. Large central bulb. No record of test of muscles. Sciatic and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation very unsatisfactory and imperfect.

Microscopic findings.—Transplant well united to resected nerve end. New neuraxes appear to be present in the transplant; this can not be determined definitely since silver differential staining is unsuccessful. Experiment not conclusive.

Experiment No. 180.—Rabbit No. 130; full grown; 120 days. March 10, 1919, left sciatic exposed; internal popliteal bundle freed; resected 3.4 cm. A segment of equal length taken from another rabbit, stored 20 days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal waxed, fine silk thread suture placed; centrally, good approximation; distally only fair. Wound closed. July 8, rabbit found dead in the morning; examined soon after death. Neurotrophic ulcer left heel noted. On exposing left sciatic, the nerve transplant found well in place, of good size and dull-white color and only moderately adherent to underlying muscle. Small, spindle-shaped central bulb, and slight enlargement

of central end of distal stump noted. Calf muscles fully exposed; these appear as if partly recovered; good color though not full size. Muscles could not be tested as regards functional return, because animal had been dead some time before it was examined. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good silver differentiation attained.

Microscopic findings.—In alternate cross and longitudinal sections of the operated nerve, numerous new neuraxes coming from the central stump may be traced through the transplant to the distal popliteal. In cross sections of the transplant near the central and distal wounds, there may be observed an increase of the endoneural connective tissue but no material thickening of the perineural sheaths of the funiculi. The new neuraxes are found in small groups, separated by endoneural connective tissue and are equally distributed through all parts of the transplant.

Experiment No. 181.—Rabbit No. 114; full grown; 145 days. December 24, 1918, left sciatic exposed; internal popliteal freed; resected 2.1 cm. A segment of equal length taken from the sciatic of another rabbit, stored 11 days in sterile liquid petrolatum at 3° C., used as transplant. Only fair central and distal approximation attained. Wound closed. May 18, 1919, rabbit found dead in the morning. Emaciated; "fungus" ears, neurotrophic ulcer left heel, which seemed to be healing; wound well healed. On exposing left sciatic, transplant found well in place, no material increase of connective tissue about operated nerve not adherent to underlying muscle. Quite distinct central bulb noted. Distal nerve presents the appearance of a normal nerve. Calf muscles fully exposed, have the appearance of regenerating muscle, though not fully recovered. Could not be tested as to functional return—animal dead. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining; silver staining faint but differential.

Microscopic findings.—Neuraxes in very good numbers pass from the distal end of the central stump, through the transplant to the distal nerve, in which they are distributed in good numbers in all of the funiculi. In cross sections of the transplant, the new neuraxes found mostly in small groups, separated by strands of endoneural tissue; quite evenly distributed over the entire transplant. Here and there small areas or columns of myelin globules and detritus, derived from the myelin sheaths of the transplanted nerve fibers, are to be found. Such areas not generally traversed by neuraxes. Very complete regeneration of the distal nerve, through the transplant, evidenced structurally.

Experiment No. 182.—Rabbit No. 114a; full grown; 145 days. December 24, 1918, right sciatic exposed; internal popliteal bundle freed; resected 2.9 cm. A segment of equal length taken from the sciatic of another rabbit, stored 11 days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal waxed, silk thread suture placed. Good central, only fair distal approximation attained. Wound closed. May 18, 1919, rabbit found dead in the morning. Large neurotrophic ulcer right heel; apparently healing. On exposing right sciatic, transplant found well in place; external popliteal looped over it, though not adherent; no material increase of connective tissue about nerves. Distinct spindle-shaped central bulb, only indistinct enlargement of central end of distal stump. Distal nerve has the appearance of normal nerve. Calf muscles exposed; not fully recovered, though present the appearance of regenerating muscle. Could not be tested as to functional return. Sciatic and transplant removed and fixed in neutral formalin. While tissues were being prepared for embedding and serial section, preparatory to staining in iron-hematoxylin and picro-fuchsin, it was accidentally thrown out, thus not available for report as to microscopic findings.

Experiment No. 183.—Rabbit No. 128; full grown; Belgian hare; 138 days. March 5, 1919, left sciatic exposed; internal popliteal freed; resected 3 cm. A segment of equal length taken from the sciatic of another rabbit, stored 22 days in sterile liquid petrolatum at 3° C., used as transplant. One central and distal waxed, fine silk-thread suture placed. Good approximation attained. Wound closed. July 21, rabbit found dead in the morning; much emaciated. Severe neurotrophic ulcer left heel. On exposing the left sciatic, transplant found well in place, of good size and of an appearance similar to resected nerve. Moderately large central bulb noted. Calf muscles still appear somewhat atrophic and of pale red color. Nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—Large numbers of neuraxes pass from distal end of central stump, through central wound and transplant, through distal wound into distal popliteal. Certain of the neuraxes passing through the transplant have acquired a myelin sheath. Spindle-shaped areas of myelin globules and granular detritus noted in longitudinal sections of the transplant. These lie between bundles of descending neuraxes. Endoneural connective tissue not materially increased; while the perineural sheaths are materially thickened. Numerous new neuraxes in the distal popliteal in all of the funiculi. Regeneration of the distal nerve evidenced structurally.

Experiment No. 184.—Rabbit No. 101; full grown; 155 days. October 8, 1918, left sciatic exposed; the internal popliteal freed; resected 3.5 cm. External popliteal bundle accidently cut while separating it from the internal popliteal; disregarded. A segment of equal length taken from the sciatic of another rabbit, stored nine days in sterile liquid petrolatum at 3°C., used as transplant. One central and one distal waxed, silk thread suture placed. Approximation of central ends fair; distally good direction, but suture not well placed, not good approximation attained. Muscle torn in exposing nerve; oozing, not fully controlled. Wound closed. March 12, 1919, killed. Rabbit in very good condition. One toe left foot missing; neurotrophic ulcer of left heel practically healed; does not spread toes of left foot on lifting up rabbit by ears. On exposing the left sciatic, transplant found well in place, of good size; quite material increase of connective tissue about operated nerve. Only indistinct central bulb. External popliteal accidently cut and not sutured, found united, slight bulbous enlargement at the place of cutting. Calf muscles and other leg muscles fully exposed, and internal popliteal and transplant completely freed from bed. On slowly cutting internal popliteal bundle central to transplant, vigorous contraction of calf muscles; same on cutting distal to transplant; no distinct response from plantar foot muscles. Plantar foot muscles have nearly recovered normal size and are of pale red color. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining; portions of calf muscles removed for gold chloride staining. Good differential silver staining attained.

Microscopic findings.—Numerous new fibers, both myelinated and nonmyelinated, pass through transplant to the distal stump. Scarcely any myelin globules, remains of myelin of transplanted nerve, to be found in the transplant. In cross sections of the transplant near both central and distal wounds, numerous neuraxes, evenly distributed over transplant, to be seen. Very little increase of endoneural connective tissue to be noted; perineural tissue not materially increased. Numerous new neuraxes in distal popliteal in all of the funiculi. In the calf muscles stained after the gold chloride method, the neuraxes of the nerve fibers of the larger muscular bundles well stained, as also in certain smaller muscular branches. Motor endings nowhere stained. This is regarded as inconclusive, and appears to be due to imperfect differentiation, since the teased muscle fibers appear to present normal structure. Regeneration and return of motor function in calf muscle, though this latter is not fully checked by histologic findings.

Experiment No. 185.—Rabbit No. 101a; full grown; 154 days. October 9, 1918, right sciatic exposed; internal popliteal freed; resected 3 cm. A segment of equal length taken from the sciatic of another rabbit, stored nine days in sterile liquid petrolatum, at 3°C., used as transplant. One central and one distal waxed, fine silk thread suture placed; good approximation attained. Wound closed. March 12, 1919, killed. Rabbit in very good condition, healed neurotrophic ulcer right heel; spread toes of right foot on elevating rabbit by ears. On fully exposing right sciatic and calf muscles, transplant found well in place with only slight increase of connective tissue about operated nerve. Transplant of good size and good color. Only slight bulbous enlargement of central stump noted. After completely freeing the operated internal popliteal and transplant, cutting the same central to the transplant, good contraction of calf muscles, contraction of foot muscles somewhat uncertain. Operated nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining; portions of calf muscles for gold chloride staining. Good silver differentiation attained.

Microscopic findings.—Numerous, both myelinated and nonmyelinated neuraxes to be traced from the distal end of the central stump to and through transplant, to distal popliteal.

In cross sections of the transplant, neuraxes seem to be evenly distributed over transplant. Narrow streaks of myelin remains, with these certain large vesicular cells, found between bundles of new neuraxes; these remains not numerous. Endoneural connective tissue not materially increased. In the gold chloride stained pieces of muscle, neuraxes well stained in the larger and smaller muscular nerves. The motor endings not differentiated; apparently due to faulty differential staining; muscle fibers present a normal structure. Regeneration of distal popliteal through transplant.

Experiment No. 186.—Rabbit No. 111; full grown; 196 days. December 20, 1918, left sciatic exposed; internal popliteal bundle freed; resected 3.0 cm. A segment of equal length taken from the sciatic of another rabbit, stored 10 days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal suture placed, waxed, fine silk thread used. Good approximation attained. Dry field; wound closed. July 4, 1919, rabbit found dead in the morning; seemed in fairly good condition the day before; severe neurotrophic ulcer left heel; healing. On exposing the left sciatic, transplant found well in place and presents the appearance of a normal nerve; no material increase of connective tissue about it. Large oval-shaped central bulb; central end of distal stump not materially increased. Distal nerve presents the appearance of a normal nerve trunk. The calf muscles exposed; they present a pale red color and are still slightly atrophic. Could not be tested as to functional return. Sciatic and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation not wholly satisfactory.

Microscopic findings.—In cross and longitudinal sections, sufficient differential silver staining of neuraxes found to determine the fact that numerous, both myelinated and nonmyelinated neuraxes, extend through the transplant from the central to the distal stump. Columns and spindle-shaped areas of myelin globules and detritus, are here and there noted in the longitudinal sections of the transplant; these show as round or oval areas in cross sections of the transplant. Apparent regeneration of the distal nerve through the transplant.

Experiment No. 187.—Rabbit No. 111a; full grown; 196 days. December 20, 1918, right sciatic exposed; internal popliteal freed; resected 2.6 cm. A segment of equal length taken from the sciatic of another rabbit, stored 10 days in sterile liquid petrolatum at 3°, C. used as transplant. One central and one distal waxed, fine silk thread suture placed; good approximation attained. Dry field; wound closed. July 4, 1919, rabbit found dead in the morning. Seemed in fairly good condition the day before; healing neurotrophic ulcer right heel. On exposing the right sciatic, it is found that the transplant is well in place of good size and color and not adherent to underlying muscle. Small, oval-shaped central bulb noted. Distal nerve presents the appearance of normal nerve trunk. Notes do not record the appearance and condition of the calf muscles. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation not wholly satisfactory.

Microscopic findings.—In cross and longitudinal sections, sufficient differentiation of neuraxes to enable determining the fact that numerous neuraxes, both myelinated and nonmyelinated, pass from the central stump through the transplant to the distal internal popliteal. Scarcely any remains of the myelin of the transplanted nerve noted. Apparent regeneration of the distal popliteal through the transplant.

Experiment No. 188.—Rabbit No. 116; full grown; 223 days. December 27, 1918, left sciatic exposed; internal popliteal freed; resected 3.1 cm. A segment of equal length taken from the sciatic of another rabbit, stored 13 days in sterile liquid petrolatum at 3° C., used as transplant. One central and distal suture placed; good approximation attained. Slight oozing of blood from distal stump into distal wound; not fully controlled. Wound closed. August 7, 1919, rabbit found dead in the morning; seemed in good condition, "fungus" ears; neurotrophic ulcer left heel, seems to be healing. On exposing the left sciatic, transplant found well in place; of good size and color; presents the appearance of normal nerve; not materially adherent to underlying muscle. Calf muscle exposed, of nearly normal size, of yellow-red color, streaked with narrow yellow stripes. Sciatic and portions of calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good silver differentiation attained throughout whole length of nerve.

Microscopic findings.—Well-developed central bulbous enlargement evidenced structurally, from the distal end of which numerous myelinated and nonmyelinated neuraxes can be

traced through the transplant to the distal popliteal. Scarcely any neuraxes in the connective tissue, surrounding the transplant, found. In cross sections of the transplant, it may be observed that the down-growing neuraxes pass through and between the old neurolemma sheaths. Endoneural and perineural connective tissue not found materially increased. Numerous new neuraxes found in all the funiculi of the distal popliteal cut at the lower level of the popliteal space. In longitudinal and cross sections of pieces of calf muscle, silver stained, new neuraxes observed in the larger muscular nerve branches, in the smaller interfascicular nerve branches and as single fibers between the muscle fibers; here and there evidence of motor nerve-endings noted. Regeneration of distal popliteal through the transplant, recovery of motor function in calf muscles, as evidenced structurally, obtained.

Experiment No. 189.—Rabbit No. 116a; full grown; 223 days. December 27, 1918, right sciatic exposed; internal popliteal freed; resected 3 cm. A segment taken from the sciatic of another rabbit, stored 13 days in sterile liquid petrolatum at 3° C., used as transplant. One central and distal waxed, fine silk thread suture placed; good approximation. Oozing in deep popliteal space, not fully controlled. Wound closed. August 7, 1919, rabbit found dead in the morning; seemed in good condition, "fungus" ears; severe neurotrophic ulcer right heel; apparently healing. On exposing right sciatic, transplant found well in place; of good size and color; surrounded by relatively dense connective tissue, adherent to underlying muscle. Calf muscles fully exposed; are of good size, yellow-red color, with narrow yellow streaks evident. Sciatic and transplant, with portions of calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining throughout.

Microscopic findings.—Distinct, large spindle-shaped central bulb, from the distal end of which numerous new neuraxes pass through the transplant to the distal popliteal. Scarcely any neuraxes course in the connective tissue outside of the perineural sheaths of the transplanted nerve. In cross sections of the transplanted nerve it may be observed that new neuraxes are distributed quite evenly over the entire transplant. In the distal popliteal lower level of the popliteal space, numerous neuraxes, both myelinated and nonmyelinated, found in all of the funiculi. In sections of the calf muscles, both in cross and longitudinal sections, new down-growing neuraxes found in the larger and smaller muscular branches and as single terminal nerve fibers on and between the muscle fibers. Regeneration of the distal popliteal through transplant and recovery of the motor fibers in the calf muscle.

Experiment No. 190.—Rabbit No. 115; full grown; 235 days. December 26, 1918, left sciatic exposed; internal popliteal freed; resected 2.9 cm. A segment of equal length taken from the sciatic of another rabbit, stored 13 days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal suture placed, waxed, fine silk thread suture; approximation good. Dry field; wound healed. August 18, 1919, killed. Rabbit in good condition; holds head to left side; when attempting to walk forward rolls over; some semicircular canal condition not pertinent to experiment. On exposing the left sciatic, transplant found well in place; presents appearance of normal nerve, though not as distinctly bounded; only moderate increase of connective tissue about transplant. Distinct central bulb; only slight enlargement of central end of distal stump. External popliteal adherent to operated internal popliteal; cut and in part resected. Calf muscles fully exposed; these present nearly normal size and color. After completely freeing operated internal popliteal and transplant from bed and slowly cutting with scissors internal popliteal central to the transplant, vigorous contraction of the muscles and movement of toes; the same on cutting distal to the transplant. Sciatic nerve and transplant and portions of calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Only in part good silver differentiation attained.

Microscopic findings.—Large spindle-shaped bulb, to which is adherent the external popliteal. From the distal end of the central bulbous enlargement on the internal popliteal, numerous myelinated and nonmyelinated neuraxes can be traced through the transplant to the distal popliteal. A few small funiculi of nerve fibers found in the connective tissue outside of the perineural sheaths of the transplanted nerves, on the side toward the adherent external popliteal. In the distal popliteal, new neuraxes in large numbers in all of the funiculi. In sections of the calf muscles, neuraxes noted in the larger and smaller intramuscular branches.

Regeneration of the distal popliteal through the transplant with regeneration of motor nerves to the calf muscles. Interossei not removed and studied.

Experiment No. 1919.—Rabbit No. 115a; full grown; 235 days. December 26, 1918, right sciatic exposed; internal popliteal freed; resected 3 cm. A segment of equal length taken from the sciatic of another rabbit, stored 13 days in sterile liquid petrolatum at 3° C., used as transplant. One central and distal waxed, fine silk thread suture placed; good approximation. Dry field; wound closed. August 18, 1919, killed. Good general condition; holds head to left side; when attempting to walk, falls to side. On exposing the right sciatic, transplant found well in place; presents the appearance of a normal nerve; external popliteal adherent. Large central bulb; central end of distal segment distinctly enlarged. On exposing calf muscles, which are nearly of normal size and color, and completely freeing the internal popliteal and transplant from its bed, slowly cutting with scissors the internal popliteal central to the transplant, causes feeble contraction of calf muscles; more vigorous contraction on cutting distal to the transplant; contraction and movement of toes doubtful. Sciatic and transplant and portions of calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Only in part good differential silver staining attained.

Microscopic findings.—Large central bulb, which tapers into transplant. From the distal end of bulb, numerous myelinated and nonmyelinated neuraxes traced through the transplant to the distal popliteal. Scarcely any neuraxes found in the connective tissue outside of the perineural sheaths of the transplanted nerve. These perineural sheaths found quite distinctly thickened. All of the funiculi of the distal popliteal nerve possess numerous new neuraxes, many of which are myelinated. In sections of the calf muscles, new neuraxes found in the intramuscular branches and as single terminal branches on the muscular fibers. Regeneration of distal popliteal through the transplant, also motor nerves in the calf muscles.

Experiment No. 192.—Rabbit No. 113; full grown; 238 days. December 23, 1918, left sciatic exposed; internal popliteal freed; resected 2.5 cm. A segment of equal length taken from the sciatic of another rabbit, stored 11 days in sterile liquid petrolatum at 3° C., used as transplant. One central and distal waxed, silk thread suture placed; approximation central good; distal good direction, but transplant twisted one-half spiral. Field not quite dry; wound closed. August 18, 1918, killed. Rabbit not in good condition; "fungus" ears; emaciated; neurotrophic ulcer left heel, not completely healed. On exposing left sciatic, it is noted that muscles of thigh look pale and flabby. Transplant found well in place; good size and color; no material increase of connective tissue about it; well-developed central bulb; quite distinct enlargement of central end of distal stump. Calf muscles fully exposed; these are small and of pale color. After freeing nerve and transplant from bed and on cutting slowly with scissors nerve central to transplant, feeble but distinct contraction of calf muscles and movement of toes noted; also on cutting distal to transplant. Sciatic and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Differential silver staining very good in part; granular deposit obscures in part.

Microscopic findings.—Large central bulb from the distal end of which numerous new neuraxes can be traced to distal popliteal, in which to the level of entrance of branches into the calf muscles new neuraxes are found in large numbers in all of the funiculi. Scarcely any neuraxes found in the connective tissue outside of the perineural sheaths of the transplanted nerves. Portions of calf muscle, in this experiment, were accidently lost. Regeneration of distal popliteal to level of calf muscles through the transplant.

Experiment No. 193.—Rabbit No. 113a; full grown; 238 days. December 23, 1918, right sciatic exposed; internal popliteal bundle freed; resected 2.4 cm. A segment of equal length taken from the sciatic of another rabbit, stored 11 days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal suture of waxed, fine silk thread placed; good approximation. Dry field; wound closed. August 18, 1919, killed. Rabbit not in good condition; much emaciated; neurotrophic ulcer right heel; not completely healed. On exposing the right sciatic, external popliteal found free; transplant well in place; good size and color; connective tissue not materially increased about it. Calf muscles fully exposed; these appear small and of pale red color. After freeing nerve and transplant completely, on slowly cutting nerve with scissors central to the transplant, good contraction of the calf

muscles and distinct movement of the toes noted, the same on cutting distal to the transplant. Sciatic and transplant and portions of calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation only in part successful.

Microscopic findings.—From the distal end of a long, spindle-shaped central enlargement embracing the central wound, numerous myelinated and nonmyelinated neuraxes traced through the transplant to the distal popliteal, in which new neuraxes are found in large numbers in all of the funiculi. Scarcely any neuraxes found in the connective tissue surrounding the transplant. Pieces of calf muscle accidently lost. Regeneration of distal popliteal through transplant.

Experiment No. 194.—Rabbit No. 110; full grown; 242 days. December 19, 1918, left sciatic exposed; internal popliteal freed; resected 2.5 cm. A segment of equal length taken from the sciatic of another rabbit, stored eight days in sterile liquid petrolatum at 3° C., used as transplant. One central and one distal suture of waxed, fine silk thread used; good approximation; dry field; wound closed. August 18, 1919, killed. Rabbit in good condition; walks well; neurotrophic ulcer left heel very nearly healed. On exposing the left sciatic, the external popliteal found in very close approximation to operated internal popliteal. The transplant found well in place; good size and color, no material increase of connective tissue about the operated nerve. Distinct central bulb and distinct enlargement of central end of distal popliteal. Calf muscles and plantar foot muscles fully exposed; these of normal size and color. After completely freeing the operated nerve from bed, slowly cutting the nerve central to transplant, continued and vigorous contraction of calf and plantar foot muscles; the latter exposed so that contraction was directly observed. Sciatic and transplant and portions of calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Fair silver differentiation attained.

Microscopic findings.—From distinct bulbous enlargement of the central stump, numerous myelinated and nonmyelinated neuraxes traced through the transplant to the distal popliteal, through which they are traced to the level of entrance to calf muscles. Scarcely any neuraxes in the connective tissue surrounding the transplanted nerve segments. Numerous neuraxes noted in the intramuscular branches in the sections of the calf muscles. Regeneration of distal popliteal through the transplant, recovery of calf muscles.

Experiment No. 195.—Rabbit No. 110a; full grown; 242 days. December 19, 1918, right sciatic exposed; internal popliteal freed; resected 3 cm. A segment of equal length taken from the sciatic of another rabbit, stored in liquid petrolatum eight days at 3° C., used as transplant. One central and distal suture of waxed, fine silk thread used; good approximation; field not quite dry; wound closed. August 18, 1919, killed. Rabbit in very good condition; uses right hind foot well; neurotrophic ulcer on right heel very nearly healed. On exposing right sciatic, external popliteal quite free, resected. The transplant found well in place; good size and color, no material increase of connective tissue about it. Distinct central bulb and quite distinct enlargement of central end of distal popliteal. Calf muscles and plantar foot muscles fully exposed; these of normal size and color. After freeing transplant and nerve from bed, on slowly cutting with scissors central to the transplant, good contraction of foot and calf muscles noted. Sciatic and transplant and portions of calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Only partially successful silver differentiation attained. This owing to fact that while this and several other series were being embedded in paraffin, steam escaped into chamber containing paraffin dishes with tissues. Sufficient silver differentiation obtained to enable determination of the neuraxes, though these are not distinctly stained.

Microscopic findings.—Large spindle-shaped central bulb, from the distal end of which numerous neuraxes, myelinated and nonmyelinated, can be traced through the transplant to the distal popliteal, in which neuraxes in large numbers are found in all of the funiculi. In sections of the calf muscles, neuraxes noted in the larger and smaller calf muscles and as single terminal nerve branches between and on the muscle fibers. Regeneration of distal popliteal through the transplant, and recovery of motor nerves in calf muscles.

Experiment No. 196.—Rabbit No. 103; large; full grown; Belgian hare; 286 days. November 5, 1918, left sciatic exposed; internal popliteal freed; resected 3 cm. A segment of equal length taken from the sciatic of another rabbit, stored 36 days in sterile liquid petro-

latum at 3° C., used as transplant. One central and one distal waxed, fine silk-thread suture placed. Centrally one funiculus of central stump not in good approximation; distally good approximation attained. Dry field; wound closed. August 18, 1919, killed. Rabbit in good condition; walks well; neurotrophic ulcer left heel very nearly healed. On exposing left sciatic, external popliteal found in close apposition to operated internal popliteal. Transplant found well in place; good size and color, very little connective tissue increase about it. Only small, indistinct central bulbous enlargement noted, distally scarcely any enlargement. Calf muscles fully exposed; these have the appearance of normal muscle. After completely freeing transplant and nerve, on slowly cutting nerve with scissors central to transplant, vigorous contraction of calf muscles and movement of toes noted. Sciatic and transplant and portions of calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Only partially successful silver differentiation attained.

Microscopic findings.—Not well marked central bulbous enlargement noted, in the center of which an accumulation of small cells, not clearly defined in silver stain, but presenting the appearance of a small localized pus pocket, is noted. From the distal end of this bulbous enlargement, numerous neuraxes, both myelinated and nonmyelinated, can be traced through the transplant to the distal popliteal. In cross sections of the transplant, approximately 1 cm. from the central wound, an accumulation of small cells under the perineural sheath is noted; possibly a small focus of pus cells. Perineural and endoneural connective tissue of the transplant found materially increased. Numerous small nerve bundles in the connective tissue outside of perineural sheaths observed. Muscle pieces came in contact with water while in paraffin; silver differentiation unsuccessful. Regeneration through transplant, although this gives evidence of having been slightly infected, of the distal popliteal to the level of muscular branches to calf muscles, more distally not controlled histologically.

Experiment No. 197.—Rabbit No. 103a; large; full grown; 286 days. November 5, 1918, right sciatic exposed; internal popliteal freed; resected 2.5 cm. A segment of equal length taken from the sciatic of another rabbit, stored 36 days in liquid petrolatum at 3° C., used as transplant. One central and distal waxed, fine silk-thread suture placed; good approximation; dry field; wound closed. August 18, 1919, killed. Rabbit in very good condition; small healing neurotrophic ulcer left heel. On exposing the right sciatic, external popliteal found in close apposition to operated internal popliteal. Transplant found well in place, good size and color; very little increase of connective tissue about it. Only small central bulbous enlargement noted. Observations necessarily and unavoidably interrupted at this point; before they could be resumed sufficient time had elapsed to make it impossible to obtain contraction of muscles supplied by unoperated external popliteal. Calf muscles presented the appearance of normal muscles, both as to size and color; return of function could not be tested. Sciatic and portions of calf muscles removed, fixed in ammoniated alcohol for pyridine-silver staining. Only partial silver differentiation attained.

Microscopic findings.—Silver differentiation sufficient to determine the fact that neuraxes, both myelinated and nonmyelinated, pass through the transplant to the distal popliteal, where they were traced to and into the muscular branches of the calf muscles. In cross sections of the transplant it is observed that very few neuraxes pass distally in the connective tissue surrounding the transplanted nerve segment. In cross sections of the distal popliteal, numerous neuraxes to be observed in all of its funiculi. Regeneration of distal popliteal through the transplant to the calf muscles.

Experiment No. 198.—Rabbit No. 120; full grown; 2 days. January 10, 1919, left sciatic exposed; internal popliteal freed; resected 2.5 cm. A segment of equal length taken from the sciatic of another rabbit, and stored 11 days at room temperature in sterile 50 per cent alcohol, used as transplant. Before use, nerve was taken from alcohol and placed for 15 minutes in warm, sterile saline solution. One central and distal waxed fine silk thread suture placed; good approximation; slight oozing from central stump, not fully controlled; wound closed. January 12, rabbit found dead in the morning. On exposing sciatic, dry field noted. Transplant found well in place, of dull gray-green color; sutures in place. Ends of resected nerve found congested. Sciatic with transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver staining very pale.

Microscopic findings.—In longitudinal sections of the transplanted nerve segment the neurolemma sheaths of the nerve fibers distinctly made out; in myelin in many places traces of Golgi funnels; neuraxes not found segmented but staining very lightly, having even borders and of approximately normal size. In cross sections outline of nerve fibers well maintained, distinctly bounded by neurolemma sheaths; myelin scarcely stained; neuraxes centrally placed in fibers and staining very lightly.

Experiment No. 199.—Rabbit No. 120a; full grown; 2 days. January 10, 1919, right sciatic exposed; internal popliteal freed; resected 3.3 cm. A segment of equal length taken from the sciatic of another rabbit, stored 11 days at room temperature in sterile 50 per cent alcohol, used as transplant. Before use, placed in warm, sterile saline solution for one hour. One central and distal waxed fine silk thread suture placed; good approximation. Wound closed. January 12, rabbit found dead in the morning. On exposing right sciatic, transplant found well in place, sutures evident. Transplant of dull gray-green color, and found not adherent to surrounding tissues. Nerve and transplant removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In longitudinal sections of the transplant, the neurolemma sheaths of the nerve fibers found well maintained; neurokeratin net of myelin only faintly stained. Neuraxes found not segmented. In longitudinal sections embracing the central and distal wounds, respectively, inwandered leucocytes in ends of the transplant distinctly observed. These inwandered cells extend for a distance of about 2 mm., both at the central and distal ends of the transplant, mainly between the nerve fibers, certain few within the neurolemma sheaths of the transplanted nerve fibers. No neurolemma sheath cells of transplanted nerves clearly made out.

Experiment No. 200.—Rabbit No. 123; full grown; 23 days. January 18, 1919, left sciatic exposed; internal popliteal freed; resected 2.8 cm. A segment of equal length taken from the sciatic of another rabbit, stored 17 days at room temperature in sterile 50 per cent alcohol, used as transplant. Before use, placed in sterile, warm saline solution 10 minutes. One central and distal waxed, fine silk thread suture placed; good approximation. Wound closed. February 10. Died, nerve taken out just after death of rabbit; still warm; beginning neurotrophic ulcer left heel. Wound well healed. On exposing the left sciatic, transplant found well in place, united to resected nerve ends; of slightly smaller diameter in middle portion than at ends; no material increase of connective tissue about transplant. Distinct, central bulbous enlargement noted. The nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver staining differential but faint.

Microscopic findings.—Numerous neuraxes extend from distal end of the central stump, through central wound into the central end of the nerve transplant, in which they may be traced distally for a distance of approximately 2 cm. In cross sections of the middle of the transplant small groups of neuraxes found within as well as outside of the neurolemma sheaths are to be observed. Neurolemma sheaths in certain regions widely distended or broken down. In such regions myelin globules, granular detritus, and large vesicular cells enclosing what appears to be lipoid globules encountered. Perineural sheaths of transplant well maintained, not materially thickened. No neuraxes found in the connective tissue outside of this sheath. New neuraxes have not reached the distal stump; this shows nerve fibers in process of degeneration.

Experiment No. 201.—Rabbit No. 123a; full grown; 23 days. January 18, 1919, right sciatic exposed; internal popliteal freed; resected approximately 3 cm. A segment of equal length taken from the sciatic of another rabbit, stored 17 days in 50 per cent alcohol at room temperature, used as transplant. One central and one distal suture placed. While manipulating transplant, central suture pulled out; transplant resected and resutured, final length approximately 2 cm.; good approximation. Wound closed. February 10, died. Nerve taken out just after death; still warm. Wound well healed. On exposing the right sciatic, transplant found well in place; united to resected nerve ends, of good size and dull gray-green color. Distinct central bulbous enlargement noted. Nerve and transplant removed and fixed in neutral formalin. Sections stained in safranine and licht grün.

Microscopic findings.—Transplant found well united to central and distal resected ends of internal popliteal; only narrow connective tissue wounds evident. In longitudinal sections of the transplanted nerve segment, strands of syncytial nucleated protoplasmic bands, apparently extending from the distal end of the central stump into the transplant, are found separated by narrow areas or columns of myelin globules, granular detritus, and vesicular cells with lipoid globules, the remains of the myelin of the transplanted nerve fibers. This structure extends to the distal end of the transplant, where, near the distal wound, the protoplasmic bands are more widely separated and less numerous, the intervening spaces wider. The central end of the distal stump presents the appearance of a nerve in degeneration.

Experiment No. 202.—Rabbit No. 118; full grown; 42 days. December 28, 1918, left sciatic exposed; the internal popliteal bundle freed; resected 2.4 cm. A segment of equal length taken from the sciatic of another rabbit, stored seven days at room temperature in sterile 50 per cent alcohol, used as transplant. Before use, nerve placed in sterile, warmed saline solution ten minutes. One central and one distal waxed, fine silk thread suture placed. Good approximation attained, though the transplanted nerve segment is of distinctly smaller diameter than the resected nerve. Wound closed. February 8, 1919, killed. Rabbit not in good condition; "fungus" ears; emaciated; neurotrophic ulcer left heel. Wound well healed. On exposing the left sciatic, the external popliteal found adherent to operated internal popliteal. Transplant found well in place; of yellow-white color; adherent to underlying muscle. Large central bulbous enlargement. Distal nerve presents the appearance of a degenerated nerve. Nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining throughout.

Microscopic findings.—In longitudinal sections of central and distal wounds, the transplant well united to resected nerve ends, little connective tissue intervening. From the distal end of the central bulb, numerous neuraxes may be traced into the central end of the transplant, in which they end distally, grouped mainly to one side in the transplant, along the inner surface of its perineural sheath; only a few scattered bundles of neuraxes in the substance of the transplant. In the transplant areas and columns of myelin globules, granular detritus and masses of large vesicular cells, with lipoid globules. The downgrowing neuraxes traced to and through the distal wound, only a few having reached the central end of the distal popliteal, in which they may be traced distally for a distance of about 1 cm.

Experiment No. 203.—Rabbit No. 118a; full grown; 42 days. December 28, 1918, right sciatic exposed; the internal popliteal freed; resected 2.5 cm. A segment of equal length taken from the sciatic of another rabbit, stored seven days in sterile 50 per cent alcohol at room temperature, used as transplant. One central and distal waxed, fine silk thread suture placed. Good central approximation attained, distal good direction, end of transplant twisted one half turn. Wound closed. February 8, 1919, killed. Rabbit not in good condition; "fungus" ears; emaciated; neurotrophic ulcer right heel. Wound well healed. Right sciatic exposed. External popliteal found adherent. Transplant found well in place; of yellow-white color, clearly demarked; adherent to underlying muscle. Large central bulb. Nerve and transplant removed and fixed in neutral formalin. Sections stained in safranine and licht grün.

Microscopic findings.—In longitudinal sections of central and distal wounds, the transplant found well united to resected nerve ends. New nerve fibers and nucleated, syncytial protoplasmic bands extend from distal end of the central stump into the transplant. In longitudinal sections of the transplant, larger and smaller bundles of syncytial protoplasmic bands, having in the main a longitudinal direction, but here and there anastomosing, and separated by areas and columns of large vesicular cells, are to be observed. In cross sections of the transplant about 1 cm. distal to central wound, one relatively large bundle of syncytial protoplasmic bands, placed largely to one side, but extending into the middle of the transplant, is recognized. Fewer of these nucleated protoplasmic bands seen in the distal part of the transplant, but may be traced to and into the distal wound. The distal nerve presents the appearance of a degenerated nerve.

Experiment No. 204.—Rabbit No. 121; full grown; 70 days. January 14, 1919, left sciatic exposed; internal popliteal freed; resected 3.2 cm. A segment of equal length taken

from the sciatic of another rabbit, stored 14 days in sterile 50 per cent alcohol at room temperature, used as transplant. Before use, the nerve placed for eight minutes in sterile, warmed saline solution. One central and distal waxed, fine silk thread suture placed. Central approximation recorded as good, distal "fair." Wound closed. March 25, rabbit found dead in the morning. Had had convulsions previous day; much emaciated; severe neurotrophic ulcer left heel. Wound well healed. On exposing the left sciatic, transplant found well in place, of light yellow-white color, of smaller size than when used; no material increase of connective tissue about it. Relatively large central bulb noted. The nerve and the transplant removed and fixed in neutral formalin. Sections stained in safranine and licht grün.

Microscopic findings.—No distinct central bulb evidenced structurally. New nerve fibers and syncytial protoplasmic strands extend from the distal end of the central stump into the nerve transplant, in the proximal half of which these are arranged in small bundles, within the perineural sheaths of the nerve transplant, with relatively few myelin globules and vesicular cells separating such bundles. In the distal half of the transplant these small bundles of nucleated protoplasmic bands are separated by larger and smaller areas or columns of vesicular cells and myelin globules. Many of the nucleated protoplasmic bands reach and penetrate the distal wound. The distal popliteal found degenerated; numerous nucleated, syncytial protoplasmic strands noted; relatively few myelin globules are evident.

Experiment No. 205.—Rabbit No. 121a; full grown; 70 days. January 14, 1919, right sciatic exposed; internal popliteal freed; resected 3.3 cm. A segment of equal length taken from the sciatic of another rabbit, stored 14 days in sterile 50 per cent alcohol at room temperature, used as transplant. Nerve placed in sterile, warmed saline solution forty-five minutes before use. One central and distal waxed, fine silk thread suture placed; good approximation. Wound closed. March 25, rabbit found dead in the morning; much emaciated; severe neurotrophic ulcer right heel. Wound well healed. On exposing the right sciatic, transplant found well in place, of light yellow-white color, much smaller diameter than when used; not adherent. Large central bulb. Nerve and transplant removed and fixed in neutral formalin. Sections stained in safranine and licht grün.

Microscopic findings.—Transplant well united to resected nerve ends. Distinct central bulb evidenced structurally, from the distal end of which numerous new nerve fibers and nucleated, syncytial strands extend into the transplant, extending to and into the distal wound. In the distal end of the transplant, areas and columns of large vesicular cells found between protoplasmic strands. The distal nerve presents the appearance of a degenerated nerve.

Experiment No. 206.—Rabbit No. 119; full grown; 62 days. January 9, 1919, left sciatic exposed; internal popliteal freed; resected 3 cm. A segment of equal length taken from the sciatic of another rabbit, stored 10 days at room temperature in sterile 50 per cent alcohol, used as transplant. Nerve, before use, placed fifteen minutes in sterile, warmed saline solution. One central and distal suture of waxed, fine silk thread placed; good approximation. Field not quite dry; wound closed. March 12, rabbit found dead in the morning. Not much emaciated; severe neurotrophic ulcer left heel. Wound well healed. On exposing the left sciatic, external popliteal found closely adherent to operated internal popliteal. Transplant found well in place, in part of light pink color in part dull white color; no material increase in connective tissue surrounding operated nerve. Large central bulbous enlargement, adherent to underlying muscle. Nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Throughout, good differential neuraxis staining attained.

Microscopic findings.—The transplant found well united to resected nerve ends. From the distal end of the central bulb, numerous down-growing neuraxes found growing distally through central wound to central end of transplant. In cross sections of the transplant about 1 cm. distal to central wound, numerous small bundles of neuraxes, separated by endoneural connective tissue are to be found. In cross sections taken near the distal wound, essentially the same structural appearance observed for the greater part of the transplant; to one side, within perineural sheath, a relatively large area, containing large vesicular cells and granular detritus noted. In this field no neuraxes observed. New neuraxes traced through the distal wound into the distal nerve segment, in which they may be traced in good numbers for a

distance of about 2 cm. Regeneration of proximal end of distal nerve through the nerve transplant.

Experiment No. 207.—Rabbit No. 119a; full grown; 62 days. January 9, 1919, right sciatic exposed; internal popliteal bundle freed; resected 2.2 cm. A segment of equal length taken from the sciatic of another rabbit, stored at room temperature in sterile 50 per cent

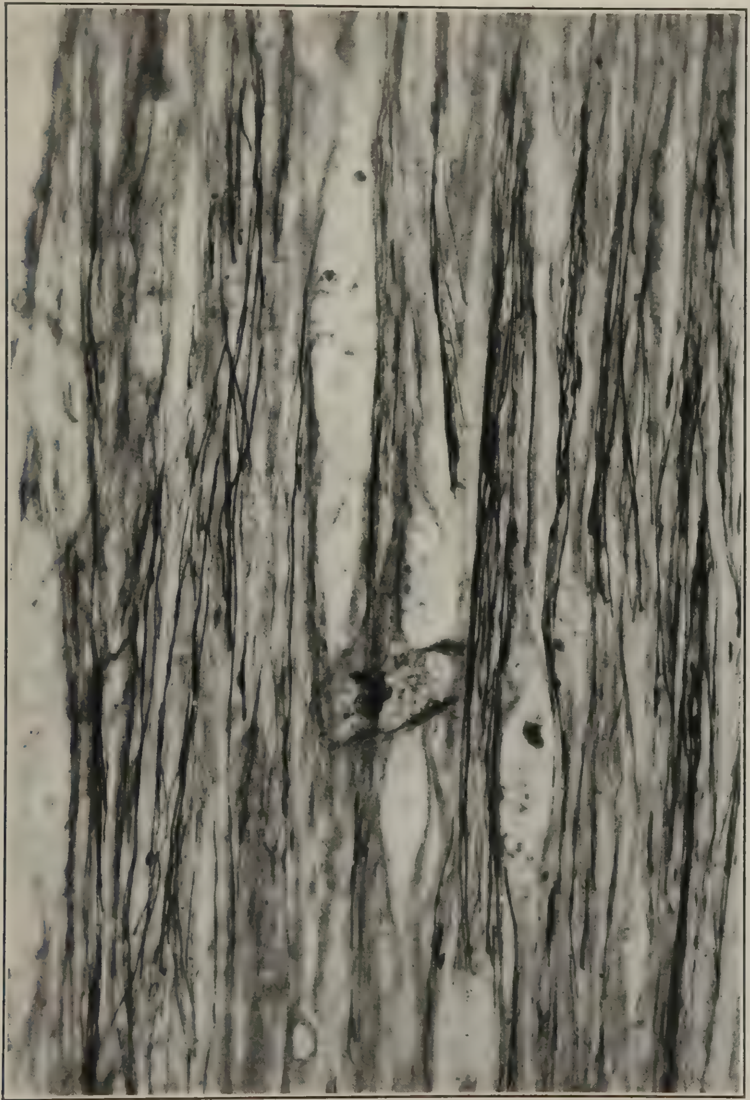

Fig. 231.—From a longitudinal section of homo-nerve transplant, stored in 50 per cent alcohol for 10 days before use as transplant; Experiment No. 206. Nerve removed 62 days after operation. Note the regular course of the new neuraxes, evident as black lines, as they pass distally within the neurolemma sheaths of the transplanted nerve fibers

alcohol for a period of 10 days, used as transplant. Nerve placed in sterile, warmed saline solution one hour and ten minutes before use. One central and distal waxed, fine silk thread suture placed. Central suture torn out; resected and resutured; approximation good. Field not quite dry; wound closed. March 12, rabbit found dead in the morning; not much emaciated; severe neurotrophic ulcer right heel. Wound well healed. On exposing the right

sciatic, external popliteal found closely adherent to operated internal popliteal. The transplant found well in place; relatively small diameter; not adherent to underlying muscle. Central end of transplant of dull white color; distal of light pink color. Large, oval-shaped central bulb. Nerve and transplant removed and fixed in neutral formalin. Sections stained in safranine and licht grün.

Microscopic findings.—Transplant found well united to the resected nerve ends; narrow connective tissue wounds. From the distinct central bulb, new small nerve fibers and

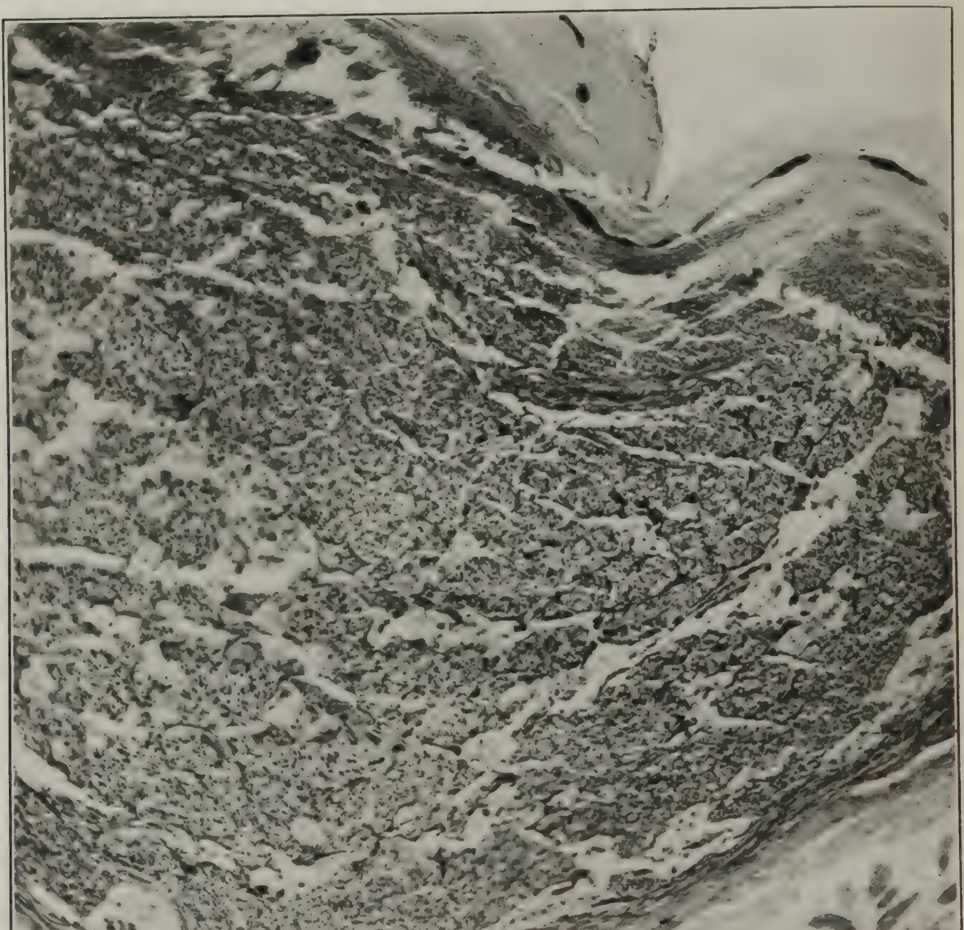

Fig. 232.—From a cross section of homo-nerve transplant, stored in 50 per cent alcohol for 10 days before use as transplant; Experiment No. 206. Nerve removed 62 days after operation. Section made approximately 15 mm. distal to the central wound. Note the numerous central neuraxes seen in cross section, showing as fine darkly stained points, very evenly distributed through the field. There is here evident excellent neurotization of the transplanted nerve segment

nucleated, protoplasmic bands extend into the transplant in which they may be traced to and through the distal wound. Especially in the longitudinal sections taken from the distal half of the transplant, irregular columns and areas of large vesicular cells and cell detritus, separating bundles of new nerve fibers, are to be noted.

Experiment No. 208.—Rabbit No. 135; large; old; Belgian hare; 67 days. March 18, 1919, left sciatic exposed; internal popliteal freed; resected 3.5 cm. A segment of equal length taken from the sciatic of another rabbit, stored at room temperature for 28 days in sterile 50 per cent alcohol, used as transplant. Nerve placed in sterile saline solution 15

minutes before use. One central and distal waxed, fine silk thread suture placed; good approximation. Dry field; wound closed. May 24, rabbit found dead in the morning; not much emaciated; severe neurotrophic ulcer left heel. Wound well healed. On exposing the left sciatic, external popliteal found free. Transplant well in place, found only moderately adherent to underlying muscle; of yellow-white color, tinged here and there a brown color. Distinct central bulb; central end of distal nerve enlarged. Nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation not successful throughout.

Microscopic findings.—Transplant well united to resected nerve ends. The silver differentiation of sufficient clearness to determine the fact that many new neuraxes coming from the distal end of the central bulb pass to and through the transplant. These are seen to descend mainly along the inner surface of the perineural sheath and peripheral part of the main funiculus, the core of which is occupied by a relatively large area containing large vesicular cells and granular detritus. Few, if any, of the down-growing neuraxes appear to have reached the distal segment of the resected nerve, which presents the appearance of a degenerated nerve.

Experiment No. 209.—Rabbit No. 122; full grown; 144 days. January 16, 1919, left sciatic exposed; internal popliteal bundle freed; resected 3.0 cm. A segment of equal length taken from the sciatic of another rabbit, stored at room temperature for a period of 15 days in sterile 50 per cent alcohol, used as transplant. Before use placed in warmed, sterile saline solution 15 minutes. One central and distal waxed, fine silk thread suture placed; good approximation attained. Wound closed. June 9, rabbit found dead in the morning; not much emaciated; small neurotrophic ulcer left heel. Nerve and transplant removed, fixed in ammoniated alcohol for pyridine-silver staining. Fair silver differentiation attained; not well embedded, sections torn.

Microscopic findings.—Transplant found well united to the resected nerve ends. From the distal end of the central bulb, numerous neuraxes are found to pass to the transplant in which they are arranged in small bundles separated by endoneural connective tissue, present in much greater amount than in a normal nerve trunk. To one side of transplant, remains of the transplanted nerve fibers noted particularly in cross sections. Neuraxes of the transplant pass to and through the distal wound and are found in good numbers in the distal nerve. Regeneration of the central end of the distal segment through the transplant.

Experiment No. 210.—Rabbit No. 122a; full grown; 144 days. January 16, 1919, right sciatic exposed; internal popliteal freed; resected 2.5 cm. A segment of equal length taken from the sciatic of another rabbit, stored at room temperature for 15 days in sterile 50 per cent alcohol, used as transplant. Before use, nerve placed for one hour in warmed, sterile saline solution. One central and distal waxed, fine silk thread suture placed; distal resutured, first very unsatisfactory; good approximation attained. Small blood clot in the connective tissue near distal wound. Wound closed. June 9, rabbit found dead in the morning; not much emaciated; moderately large neurotrophic ulcer right heel. On exposing the right sciatic, external popliteal found free. Transplant found well in place; of good size; only moderately adherent to underlying muscle. Large central bulb. The nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Fair silver differentiation attained; tissue not well embedded, sections torn.

Microscopic findings.—Neuraxes coming from the distal end of the central bulbous enlargement can be traced through the transplant into the distal segment of the resected nerve in which they are present in large numbers. Within the transplant, these down-growing neuraxes are arranged in small bundles, separated by endoneural connective tissue, present in larger amount than in a normal nerve trunk. Regeneration of the distal nerve segment through the nerve transplant attained.

Experiment No. 211.—Rabbit No. 137; small rabbit; seemed full grown; 152 days. March 19, 1919, left sciatic exposed; internal popliteal freed; resected 2.5 cm. A segment of equal length taken from the sciatic of another rabbit, stored for a period of 29 days at room temperature in sterile 50 per cent alcohol, used as transplant. Before use, nerve placed for 10 minutes in warmed, sterile saline solution. One central and distal waxed, fine silk thread suture placed. Good central approximation attained; a small amount of

clotted blood in central wound; distally, good direction, but distal end of transplant twisted one half turn. Wound closed. August 18, killed. Rabbit in good condition; not large, but appears well fed; neurotrophic ulcer left heel, which appears to be healing. On exposing the left sciatic, external popliteal found in close approximation to the operated internal popliteal. Transplant found well in place, of good size; has the appearance of a normal nerve, though of slightly brown color. No distinct central bulbous enlargement noted. Calf muscles fully exposed, these present a pale red color but have not fully recovered their normal size. The external popliteal cut central and distal to the region of the transplant and the internal popliteal and transplant completely freed from bed. On slowly cutting the sciatic central to the transplant good contraction of the calf muscles and slight movement of the toes noted; the same cutting distal to the transplant. The nerve and the transplant and portions of the calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation not good for distal portion of nerve.

Microscopic findings.—Numerous new neuraxes traced through the transplant into the distal portion of resected nerve to level of calf muscles. In the transplant these neuraxes in the form of small bundles separated by endoneural connective tissue. Very little detritus derived from the transplanted nerves noted. In sections of the calf muscles, numerous neuraxes observed in the intrafascicular nerve bundles and as single nerve fibers, between and on muscle fibers; a few motor nerve endings noted. In sections of the posterior tibial nerve, not successful silver differentiation. Regeneration of distal popliteal including motor branches and endings in the calf muscles attained.

Experiment No. 212.—Rabbit No. 134; full grown; not large; 154 days. March 17, 1919, left sciatic exposed; internal popliteal freed; resected 3 cm. A segment of equal length taken from the sciatic of another rabbit, stored at room temperature in sterile 50 per cent alcohol for a period of 27 days, used as transplant. Before use, nerve placed for 15 minutes in warmed, sterile saline solution. One central and distal nerve suture placed; good approximation. Wound closed. August 18, killed. Rabbit in good condition; neurotrophic ulcer left heel nearly healed. On exposing the left sciatic, the external popliteal found in close apposition to the operated internal popliteal. Transplant found well in place; of small diameter; but presents the appearance of a normal nerve; only moderately adherent to the underlying muscle. Distinct central bulb noted. Distal nerve presents the appearance of a normal nerve. Calf muscles fully exposed; these still somewhat atrophic and of pale-red color. Nerve and transplant completely freed from the bed. On cutting slowly with scissors central to the transplant, indistinct contractions—"feeble contractions"—of calf muscles noted. Nerve and transplant and portions of the calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining for central part of nerve, but not for distal part, attained.

Microscopic findings.—Numerous neuraxes can be traced from the distal end of the central stump through the transplant to the distal nerve. Silver staining of pieces of calf muscles not satisfactory—no neuraxes stained. Regeneration of distal nerve through transplant, recovery of calf muscles not confirmed by microscopic findings.

Experiment No. 213.—Rabbit No. 125; full grown; 208 days. January 22, 1919, left sciatic exposed; internal popliteal freed; resected 2.9 cm. A segment of equal length taken from the sciatic of another rabbit, stored at room temperature for 21 days in sterile 50 per cent alcohol, used as transplant. Nerve placed in sterile saline solution for 15 minutes before use. One central and distal waxed, fine silk thread suture placed; good approximation. Wound closed. August 18, killed. Rabbit in fairly good condition; healing neurotrophic ulcer left heel; walks on heel and does not bring foot down to floor. On exposing left sciatic external popliteal found free; transplant well in place; of small diameter; only slightly adherent to underlying muscle. Large and distinct central bulb noted; evident enlargement of the central end of distal nerve. Calf muscles fully exposed; these still slightly atrophic, of pale red color, streaked with light yellow bands. External popliteal resected, operated internal popliteal and transplant completely freed from bed. On slowly cutting nerve with scissors central to the transplant, feeble but distinct contraction of calf muscles noted; the same on cutting distal to transplant. No distinct movement of the toes observed. Nerve and transplant and portions of calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good differential silver staining attained.

Microscopic findings.—The distinct central bulb evidenced structurally, from the distal end of which numerous new neuraxes can be traced through the transplant to the distal nerve. Within the transplant the neuraxes arranged in the form of small funiculi separated by endoneural connective tissue. New neuraxes traced into the calf muscles in which they are found in the intrafascicular nerves and as separate nerve fibers between and on the muscle fibers. Regeneration of distal nerve through transplant, partial return of motor function in calf muscles.

Experiment No. 214.—Rabbit No. 125a; full grown; 203 days. January 27, 1919, right sciatic exposed; the internal popliteal bundle freed; resected 2.9 cm. A segment of equal length taken from the sciatic of another rabbit, stored at room temperature in sterile 50 per cent alcohol for 21 days, used as transplant. Before use, nerve kept in sterile saline solution for 50 minutes. One central and distal waxed, fine silk suture placed; good approximation. Wound closed. August 18, killed. Rabbit in fairly good condition; healing neurotrophic ulcer right heel. On exposing the right sciatic, it is found that the external popliteal is closely adherent to operated internal popliteal. The transplant found well in place and about one-half the diameter as when used; only moderately adherent to underlying muscle. Relatively large central bulb; central end of distal nerve found only slightly enlarged. Calf muscles fully exposed; these have not fully recovered size; pale red color. The nerve and the transplant completely freed and external popliteal cut in popliteal space; on slowly cutting with scissors, the nerve central to the transplant, distinct but feeble contractions of the calf muscles noted; the same on cutting distal to the transplant; no toe movement noted. Nerve and transplant and portions of calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—From the large central bulb, numerous new neuraxes can be traced through the transplant to the distal nerve and through the muscular branches to the calf muscles. Very good regeneration of motor fibers in calf muscles noted. Regeneration of distal nerve through the transplant including muscular branches to calf muscles.

Experiment No. 215.—Rabbit No. 126; full grown; 208 days. January 22, 1919, left sciatic exposed; internal popliteal freed; resected 2.6 cm. A segment of equal length taken from the sciatic of another rabbit, stored at room temperature in sterile 50 per cent alcohol for 22 days, used as transplant. Before use, nerve placed in warmed, sterile saline solution for 15 minutes. One central and distal waxed, fine silk-thread suture placed; central approximation not quite end to end, distal good. Wound closed. August 18, killed. Rabbit in good condition; small healing neurotrophic ulcer left heel; not full use of foot. On exposing the left sciatic, it is found that external popliteal is in close approximation to operated internal popliteal. Transplant found well in place; nearly of same size as when used. Distinct central bulb noted; moderate enlargement of central end of distal nerve. Calf muscles fully exposed; these have not fully recovered size. Nerve and the transplant completely freed from bed. On slowly cutting nerve central to transplant, contraction of the calf muscles noted, as also slight movement of the toes; same on cutting distal to the transplant. Nerve and transplant and portions of calf muscles removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good differential silver staining attained; pale.

Microscopic findings.—Transplant firmly united to resected nerve ends. Well-developed central bulb evidenced structurally, from the distal end of which numerous myelinated nerve fibers can be traced through the transplant to the distal nerve. In cross sections of the transplant made about 1.5 cm. distal to the central wound, it may be observed that the perineural sheaths of the transplanted nerve segment are intact and only moderately thickened, while the endoneural tissue is distinctly increased in amount. The neuraxes are found in small groups separated by endoneural tissue. In sections of the calf muscles new neuraxes are found in the interfascicular nerve bundles, and here and there as single fibers passing to the muscle fibers. Good regeneration of distal internal popliteal through the nerve transplant attained.

Experiment No. 216.—Rabbit No. 126a; full grown; 208 days. January 22, 1919, right sciatic exposed; internal popliteal freed; resected 2.9 cm. A segment of equal length taken from the sciatic of another rabbit, stored at room temperature in sterile 50 per cent cent alcohol for 22 days, used as a transplant. Before use, nerve placed in warmed, sterile

saline solution for one hour. One central and distal waxed, fine silk-thread suture placed; good approximation. Wound closed. August 18, killed. Rabbit in good condition; healing neurotrophic ulcer right heel. On exposing the right sciatic, external popliteal found closely adherent to operated internal popliteal. Transplant found well in place; of good size; of dull white color and only moderately adherent to underlying muscle. Large central bulb noted; central end of distal nerve only slightly enlarged. Calf muscles fully exposed; these appear to have nearly recovered size and color. The nerve and the transplant completely freed from bed and external popliteal cut in popliteal space. On slowly cutting with scissors the nerve central to the transplant, good contraction of the calf muscles observed. Nerve and transplant and portions of the calf muscles removed for pyridine-silver staining. Pale, but fairly good differential silver staining attained.

Microscopic findings.—Transplant found well in place and firmly united to the resected nerve ends; line of suture hardly evident. From the central bulb numerous neuraxes traced into proximal end of the transplant, relatively few traced into the connective tissue surrounding the transplant. In cross sections of the transplant taken about 1.5 cm. distal to the central wound, the epineural sheaths found materially thickened and there is noted a marked increase of the endoneural connective tissue. Within the transplant, nerve fibers, both myelinated and nonmyelinated, observed in small bundles, separated by varying amounts of endoneural connective tissue. These neuraxes can be traced through the transplant to the distal nerve within which they are present in large numbers, both myelinated and nonmyelinated fibers, and are found quite evenly distributed in the several funiculi. In sections of the calf muscles, neuraxes observed in the interfascicular nerve branches and as single nerve fibers on and between muscle fibers. Structurally considered, the muscles appear as regenerated. Fairly complete regeneration of the distal nerve through the transplant, including nerves to calf muscles, attained.

The end results of the experimental observations on stored, homo-nerve transplants are on the whole very satisfactory. Functional return is recorded for all of the experiments of longer duration. Stored homo-nerve transplants seem to serve the purpose of nerve bridge quite as well as fresh homo-nerve transplants, thus obviating in a large measure certain difficulties connected with the use of homo-nerve transplants in human surgery. If nerves obtained at amputations can be stored for weeks, to be at hand when required, with promise of favorable results on use, stored homo-nerve transplant deserves consideration in human surgery. It is our belief that smaller nerve bundles, used if necessary as cable or multiple nerve transplants, should give promise of more favorable end results than the use of one large nerve, such as the sciatic or its main branches used as a nerve bridge.

In all of the experiments (No. 150 to No. 157) in which a homogenous nerve bridge of nerve stored in vaseline was made there was noted relatively little increase in the connective tissue surrounding the nerve transplant at the time when the nerve was exposed for study of functional return. The transplant presented the appearance of a normal nerve. In all of these experiments down-growing neuraxes derived from the central stump neuraxes were traced through the central wound into the transplant, and through the transplant to and through the distal wound into the distal stump. In the cross sections of the transplants the down-growing neuraxes encountered are many of them found within what appear to be neurolemma sheaths remains of transplanted nerve fibers. Tissue detritus and large vesicular phagocytic cells, unlike the end results of Wallerian degeneration, are met with within the nerve funiculi. In the experiments of about two months' duration (No. 154 and No. 155) feeble muscle contraction was noted and interfascicular, muscular

nerve bundles with new neuraxes were noted in the sections of the calf muscles; and in experiments of nearly five months' duration (No. 156 and No. 157) regeneration of the distal segment of the nerve with down-growing neuraxes was quite complete. On the whole, very satisfactory neurotization of the degenerated distal segment was obtained in experiments dealing with homonerve transplants, stored in vaseline, following in the main the method of procedure suggested by Dujarier and François.[76] The much larger series of homogenous-nerve transplants stored in liquid petrolatum (No. 158 to No. 197) included 14 experiments of relatively short duration (1 hour to 12 days) in which the behavior of the transplant soon after it was placed as a nerve bridge could be studied. A nerve stored in liquid petrolatum at 3° C. retains its microscopic structure quite completely and will stain differentially by the pyridine-silver method. Two days and even four days after such a transplant is placed the neuraxes of the nerve fibers as seen in the pyridine-silver preparations are not fragmented. From 6 days to 12 days after transplantation the neuraxes are found segmented and show a granular change. The myelin shows fragmentation, but there is no evidence of proliferation of sheath cells. At the end of 12 days there are still found fragments of old neuraxes in the transplanted nerve segment. In the central wound region down-growing central neuraxes have penetrated the wound region and certain ones have extended into the transplant for a distance of about 2 mm. Experiments Nos. 173 and 174 deserve special consideration. A homogenous-nerve transplant stored 39 days in liquid petrolatum was used to bridge a nerve defect. The animal died 23 days after the operation but was used for histologic study. In cross sections of the transplants, made about 1 cm. distal to the central wound, new neuraxes were found in all parts of the transplant. In many parts of the field more than one neuraxis was found in one neurolemma sheath, while other neuraxes are found outside of the neurolemma sheaths. Extensive neurotization of the transplant had taken place, by downward growth of central neuraxes, at the end of 23 days after the operation. Of the experiments of this series 20 were carried on for a period of 3 months or longer; the longest for a period of nearly 7 months. In all of these experiments, where functional tests could be made, return of functions in the calf muscles is recorded, and in certain of the longer time experiments return of function in the foot interossei was observed. All of the experiments were controlled by histologic study of practically the whole sciatic nerve, and in all of the experiments could central neuraxes be traced through the transplant into the distal popliteal nerve and thence into the calf muscles. In cross sections of the transplanted nerves in the respective experiments, stained by the pyridine-silver method, it could be determined in nearly every experiment that the down-growing central neuraxes made use of the neurolemma sheaths of the transplanted nerve fibers in their course through the transplant. In all of these experiments relatively few nerve fibers are found in the connective tissue surrounding the perineural sheaths of the funiculi of the nerve transplant, interpreted as meaning that in this series the nerve transplant is the main avenue along which the down-growing neuraxes reach the distal stump. The experimental observations dealing with homogenous-nerve transplants stored in liquid petrolatum seem

to us to warrant the deduction that human nerves obtained from amputated members and stored in liquid petrolatum as here directed and, on need, used for bridging nerve defects, deserve serious consideration as a surgical procedure. We were agreeably surprised at the favorable results attained on use of homogenous-nerve transplants stored in 50 per cent alcohol for purpose of nerve bridge. In this series of 18 experiments (No. 198 to No. 216) relatively few were of short duration. In Experiments No. 198 and No. 199 the rabbit was found dead 2 days after operation. In sections of the transplant stained by the pyridine-silver method the neuraxes were found to stain very lightly, but were found unsegmented. Inwandered leucocytes were found in the ends of the transplant at the central and distal wounds, both within the neurolemma sheaths and between the nerve fibers. In Experiments No. 200 and No. 201 (compare Experiments No. 173 and No. 174) the rabbit had died 23 days after the operation but the tissue was used for histologic study. In preparations stained after the pyridine-silver method down-growing central neuraxes can be traced through the central wound and for a distance of about 2 cm. into the transplant. In cross sections of the transplant the down-growing neuraxes are found within as well as without the neurolemma sheaths, but practically no nerve fibers are found in the connective tissue surrounding the transplant, outside of the perineural sheaths. By the end of 42 days, more clearly 2 months after the operation, down-growing neuraxes were traced through the transplant to the distal wound and through this into the central end of the distal popliteal, the down-growing neuraxes decreasing in number the farther distal the observation is made. In the experiments of longer duration, 8 in number, in which the observations were carried on to from 4 months to nearly 6 months after the operation, functional return was noted in the experiments in which this could be tested and histologically new neuraxes were found in the distal nerve, conveyed there through the transplant. In several experiments new neuraxes were found in the interfascicular and intrafascicular nerve bundles of the calf muscles.

By way of summary it may here be added that very good neurotization was attained through homogenous nerve bridges which had been stored in 50 per cent alcohol. The supposition is permissible that in nerves stored in sterile vaseline and liquid petrolatum at a temperature of 3° C. there may be some degree of viability of certain tissue elements—sheath cells or connective tissue cells—even though there is no satisfactory evidence of the proliferation of the sheath cells of transplanted nerve fibers, nor of the participation of the sheath cells of the nerve transplant, direct or indirect, in the down growth of the central neuraxes. In case of nerves stored in alcohol, it can not be supposed that any viability is retained by the tissue elements or cells of the nerves transplanted. There is no evidence of sheath cell participation and no evidence that they proliferate. The fragmentation of the myelin and neuraxes of the transplanted nerves after storage in vaseline, liquid petrolatum, and alcohol is a necrobiotic change and not a secondary degeneration—Wallerian degeneration—as observed in the distal segment.

STORED HETERO-NERVE TRANSPLANTS

SERIES NO. 14

HETERO-NERVE TRANSPLANTS STORED IN LIQUID PETROLATUM

SERIES NO. 15

HETERO-NERVE TRANSPLANTS STORED IN 50 PER CENT ALCOHOL

In the discussion of Series No. 11, No. 12 and No. 13, stored homogenous transplants, consideration was given to the fact that little if any viability is retained by any of the tissue elements of nerves stored for stated periods before use as a transplant, especially so when stored in 50 per cent alcohol. Therefore, it was thought that the sheath cells of the stored, transplanted nerves take no active part in the fragmentation of the neuraxes and myelin sheaths of the transplanted nerves and, so far as can be determined, are not causally related to the downgrowth of the central neuraxes, in their passage through the transplant to reach the distal segment of the resected nerve. The conviction seems warranted that the neurolemma sheaths of the stored, transplanted nerve fibers, which do not fragment with the neuraxes and myelin sheaths, act in a purely mechanical way in serving as conduits through which the down-growing neuraxes are conveyed through the transplant to the distal nerve segment. Therefore, the supposition seemed justified that a hetero-nerve transplant, stored in liquid petrolatum and especially in alcohol, would prove more satifactory as a nerve-bridge than a fresh heterogenous nerve transplant. Series No. 14 and No. 15 were undertaken to test this hypothesis. In Series No. 14, the internal popliteal or ulnar nerve of dogs was removed under aseptic precautions and stored in liquid petrolatum, as described under Series No. 12, for periods varying for from 12 days to 25 days and were then used to bridge nerve defects caused by resecting the sciatic nerve of rabbits. One central and one distal fine waxed silk suture was placed to fix the transplant to the resected nerve ends. In Series No. 15, segments, taken from the internal popliteal and ulnar nerves of dogs and stored for periods varying from 5 days to 7 days in 50 per cent alcohol, were used to bridge nerve defects in the sciatic of rabbits caused by resection and sutured in place by fine waxed silk sutures.

The protocols of the experiments of Series No. 14 and No. 15, stored heterogenous nerve-transplants, are as follows:

PROTOCOLS

EXPERIMENT No. 217.—Rabbit No. 127a; full grown; 5 days. March 4, 1919, the right sciatic exposed; internal popliteal freed; resected 3.1 cm. A segment of equal length taken from the internal popliteal of a dog, stored for 10 days in sterile liquid petrolatum at 3° C, used as transplant. The transplant of dull white color and of larger diameter than the resected nerve. One central and distal suture of waxed, fine silk thread placed; good approximation. Dry field; wound closed. March 9, rabbit found dead in the morning. Superficial wound healed. On exposing the right sciatic, transplant is found well in place; loosely united to resected nerve ends; not adherent to surrounding muscle. Nerve and transplant removed and fixed in neutral formalin. Sections stained in safranine and licht grün.

Microscopic findings.—Longitudinal sections, embracing central and distal wounds, show very good approximation; a few extravasated blood cells found in the intervening connective

tissue. Leucocytes noted in the central and distal ends of the transplant for a distance of about 8 mm. The great majority of these found between the nerve fibers. Leucocytes have wandered in less number and for a shorter distance into the resected nerve ends. In cross and longitudinal sections of the transplant taken from its middle third, the contained nerve fibers appear as very well preserved; the neuraxes staining pale, though readily made out, and not fragmented; the myelin sheaths not fragmented; the neurolemma sheaths clearly seen. The few sheath cell nuclei here and there seen, appear in form and staining reaction much as do similar nuclei in normal nerves. The perineural sheaths present the characteristic appearance of this structure.

Experiment No. 218.—Rabbit No. 133a; large; old; Belgian hare; 82 days. March 15, 1919, right sciatic exposed; internal popliteal freed; resected 3 cm. A segment of equal length taken from the left ulnar of a dog, stored 25 days in sterile liquid petrolatum at 3° C., used as transplant. One central and distal waxed, fine silk thread suture placed; good approximation. Wound closed. June 5, killed. For several days rabbit had not been well; emaciated; nearly moribund, when killed; right heel swollen and red, no ulcer. On exposing the right sciatic, external popliteal found free. Transplant found well in place and firmly united to resected nerve ends; seemed of smaller diameter than when used; of distinct light yellow color; only moderately adherent to the underlying muscle. Large central bulb, which tapers toward the transplant; slight enlargement of central end of distal nerve noted. Calf muscles very atrophic; no response on cutting nerves. Nerve and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation attained.

Microscopic findings.—In longitudinal sections, the large central bulb clearly demarked from the transplant. In the portion of the bulb developed from the distal end of the central stump the light yellow coloring, differential staining of neuraxes characteristic for pyridine silver methods, is to be observed. The sections of the transplant throughout, present a jet-black, nontransparent coloration, by reason of which structural differentiation can not be made out. By reason of this silver reaction, it is not possible to determine whether neuraxes coming from the central stump penetrate the transplant. In cross sections of the transplant, its connective tissue sheaths present a brown-yellow color. In close relation with this sheath new neuraxes are observed. Within the sheaths, the portions containing the nerve fibers of the funiculi colored jet-black. The distal internal popliteal stump completely degenerated.

Experiment No. 219.—Rabbit No. 131a; large; full grown; 82 days. March 12, 1919, right sciatic exposed; internal popliteal freed; resected 2.8 cm. A segment of equal length taken from the right ulnar of a dog, stored in sterile liquid petrolatum at 3° C. for a period of 20 days, used as transplant. One central and distal waxed, fine silk thread suture placed. Good central approximation attained; at the distal wound, thread through transplant very nearly cut through. Wound closed. June 2, rabbit found dead in the morning; moderate emaciation; severe neurotrophic ulcer right heel. On exposing the right sciatic, it is noted that the transplant is united to central end of resected nerve, but pulled free from the distal segment, the transplant ending free 1.5 cm. distal to central wound; remaining transplant segment yellow-white color; large central bulb. The central and distal segments of the resected nerve and remains of transplant removed and placed in ammoniated alcohol for pyridine-silver staining.

Microscopic findings.—Numerous neuraxes can be traced from the distal end of the central bulb along the side of the transplanted nerve segment, but do not appear to have penetrated the same. Transplanted nerve segment clearly demarked by reason of its jet-black coloration. Distal nerve completely degenerated.

Experiment No. 220.—Rabbit No. 129a; full grown; 112 days. March 7, 1919, right sciatic exposed; internal popliteal freed; resected 2.8 cm. A segment of equal length taken from the left internal popliteal bundle of a dog, stored 14 days in sterile liquid petrolatum at 3° C., used as transplant. One central and distal waxed, fine silk thread suture placed; good approximation. The diameter of the transplant somewhat greater than that of the resected nerve. Dry field; wound closed. June 27, killed. Rabbit not well for several days; neurotrophic ulcer right heel. On exposing right sciatic, external popliteal found free.

Transplant found well in place and firmly united to resected nerve ends; seems of slightly larger diameter than when used; distinct yellow-white color, which enables demarking it clearly. Moderately large central bulb. Calf muscles atrophic. No response on cutting nerve central and distal to the transplant. Nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—Distinct central bulb evidenced structurally, from the distal end of which new neuraxes pass to the side of the transplant. The transplant itself is stained a deep black color, admitting no determination of structural details. In cross and longitudinal sections of the transplant, it is not possible to differentiate any neuraxes within the perineural sheaths of the transplant; this by reason of the dark silver reaction. In cross and longitudinal sections of the internal popliteal distal to the transplant a goodly number of new neuraxes are to be observed. In a series of longitudinal sections embracing the distal wound and adjacent nerve ends, neuraxes are to be observed entering the field of the distal wound to one side of the distal end of the transplant. It would appear, though by reason of the peculiar staining of the transplant this can not be determined conclusively, regeneration in the distal stump is attained through neuraxes that pass distally outside of the transplant.

Experiment No. 221.—Rabbit No. 130a; full grown; 121 days. March 10, 1919, right sciatic exposed; internal popliteal freed; resected 3.2 cm. A segment of equal length taken from the right ulnar of a dog, stored in sterile liquid petrolatum 17 days at 3° C., used as transplant. One central and distal suture waxed, fine silk thread placed; good approximation. The diameter of the transplant greater than that of the resected nerve. Wound closed. July 8, rabbit found dead in the morning; moderately emaciated; severe neurotrophic ulcer right heel. On exposing the right sciatic, external popliteal found free; transplant well in place; clearly demarked by reason of its light yellow color; no material increase of connective tissue about it. Large central bulb, adherent to underlying muscle, noted. Calf muscles still atrophic, present the appearance of degenerated muscle. Nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation attained.

Microscopic findings.—From the distal end of the central bulb new neuraxes can be traced mainly to one side of the transplant; some few appear to enter the transplant, but by reason of the dark, nontransparent coloration they can not be traced any distance in the transplant. No neuraxes appear to have reached the distal internal popliteal, which structurally considered has the appearance of a completely degenerated nerve.

Experiment No. 222.—Rabbit No. 129a; full grown; Belgian hare; 138 days. March 5, 1919, right sciatic exposed; internal popliteal freed; resected 3.2 cm. A segment of equal length taken from the internal popliteal of the right sciatic of a dog, stored in sterile liquid petrolatum for 11 days at 3° C., used as transplant. One central and distal waxed, fine silk thread suture placed; good approximation. Wound closed. July 21, rabbit found dead in the morning; much emaciated; severe neurotrophic ulcer right heel. On exposing the right sciatic, external popliteal found closely adherent to operated internal popliteal. Transplant found well in place; of distinct yellow-white color, thus clearly demarked. Large spindle-shaped central bulb. Calf muscles atrophic; present the appearance of degenerated muscle. Nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation not good in all parts of the series.

Microscopic findings.—From the distal end of the very well developed central bulb, numerous neuraxes passing mainly to one side of the transplanted nerve segment noted. In cross and longitudinal sections of the nerve transplant, the appearance presented in sections warrants conjecture that the chemical state of the transplanted nerve segment, which may be correlated with the peculiar jet-black coloration noted on staining with the pyridine-silver method, is undergoing a change in that the outer portion of the transplant no longer presents this peculiar coloration, only the core or central portion being thus colored. No neuraxes are to be observed within the transplant nor in the distal stump, which presents the appearance of a completely degenerated nerve.

Experiment No. 223.—Rabbit No. 135a; old; Belgian hare; 67 days. March 18, 1919, right sciatic exposed; the internal popliteal freed; resected 3.3 cm. A segment of equal

length taken from the right ulnar of a dog, stored at room temperature in sterile 50 per cent alcohol for 6 days, used as transplant. Before use, the nerve was placed in warm, sterile saline solution for 15 minutes. One central and distal waxed, fine silk thread suture placed. Wound closed. May 24, rabbit found dead in the morning; moderate emaciation; severe neurotrophic ulcer right heel. On exposing the right sciatic, the external popliteal found free. Transplant found well in place, united to resected nerve ends; clearly demarked by its yellow color; no material increase of connective tissue about it. Large spindle-shaped bulb noted. Calf muscles atrophic and flabby. Nerve transplant and nerve removed and fixed in ammoniated alcohol for pyridine-silver staining. Good neuraxes differentiation attained; tissue blocks not well embedded, sections in part torn.

Microscopic findings.—In longitudinal sections embracing the central wound, scattered neuraxes traced from the central nerve stump into central end of the transplant. In cross sections of the transplant, approximately 1.5 cm. distal to the central wound, the perineural sheath of the transplanted nerve segment is found very materially thickened; within this there is found a detritus, the remains of the transplanted nerves. In it no definite tissue can be recognized; even the neurolemma sheaths of the transplanted nerves have disappeared. No new neuraxes are to be recognized. In longitudinal sections of the transplant the same general appearances are presented, except that here and there short fragments of old neuraxes, having no definite arrangement, are found scattered through the detritus. Distal nerve completely degenerated.

Experiment No. 224.—Rabbit No. 137a; small; full grown; 152 days. March 19, 1919, right sciatic exposed; internal popliteal freed; resected 3 cm. A segment of equal length taken from the left ulnar of a dog, stored at room temperature in sterile 50 per cent alcohol for 7 days, used as a transplant. Before use, the nerve was placed for 15 minutes in a sterile saline solution. One central and distal waxed, fine silk thread suture placed; very good approximation of nerve ends. Wound closed. August 18, killed. Rabbit in good condition; small neurotrophic ulcer of the left heel. On exposing the right sciatic, external popliteal found free. Transplant found well in place; clearly demarked by its yellow-white color; good size and firmly united to resected nerve ends. Calf muscles exposed; atrophic and of a pale yellow-red color. Nerve and transplant freed from bed, on slowly cutting the nerve central to the transplant, no response of calf muscles noted; no evidence of contraction. Nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation only in part successful. Resulting sections somewhat torn.

Microscopic findings.—In longitudinal sections of the central wound region, it is to be observed that neuraxes passing from the distal end of the central bulb, pass to the region of the central wound, which they do not penetrate for any distance; certain of them turning centralward. In the central end of the transplant, near the central wound and for several millimeters distal, quite long fragments of the old neuraxes of the transplanted nerves, differentially stained in silver, may be observed; distal to this region, such neuraxes remains no longer observed. In cross and longitudinal section of the transplant 1.5 cm. to 2 cm. and 3 cm. distal to the central wound, no new neuraxes observed within the transplanted nerve segment. The nerve fibers of the transplant in part completely broken down, in part the old neurolemma sheaths found persisting, filled with detritus and leucocytes filled with lipoid globules. Just central to the distal wound, new neuraxes recognized in the transplant, passing through the distal wound into the distal popliteal in which they may be traced to the level of the calf muscles. Apparent regeneration of the distal nerve, downgrowing neuraxes appearing to pass distally mainly outside of the transplant is concluded.

Experiment No. 225.—Rabbit No. 134a; full grown; 154 days. March 17, 1919, right sciatic exposed; internal popliteal freed; resected 3.0 cm. A segment of equal length taken from the external popliteal bundle of the left sciatic of a dog, stored in sterile 50 per cent alcohol at room temperature for 5 days, used as a transplant. Before use, nerve placed 15 minutes in warmed, sterile saline solution. One central and distal waxed, fine silk thread suture placed; good approximation. Clean, dry field; wound closed. August 18, killed. Rabbit in good condition; neurotrophic ulcer on right heel nearly healed; does not use right hind leg and foot normally. On exposing the right sciatic, the external popliteal found

quite free. Transplant found well in place; demarked by light yellow color; united to resected nerve ends. Spindle-shaped central bulb noted. Calf muscles atrophic and of pale red color. Section of nerve causes no contraction of the calf muscles. Nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Very good silver differentiation attained.

Microscopic findings.—In longitudinal sections embracing the central wound, new neuraxes can be traced from the distal end of the central stump into the central end of the transplant, either as single neuraxes or as small groups of such, which course distally in collapsed neurolemma sheaths. In cross sections of the transplant approximately 1.5 cm. distal to the central wound, it may be observed that mainly to one side many new neuraxes are found within the perineural sheath of the transplant, in part within this sheath, as also in the detritus, derived from the transplanted nerve fibers. Within and between the persisting neurolemma sheaths, numerous leucocytes greatly distended with lipoid globules are to be observed. Certain of the neuraxes which are found in the transplant and its sheath are to be traced to and through the distal wound into the distal popliteal through the transplant attained.

The end results of the experiments on stored hetero-nerve transplants are, on the whole, unsatisfactory. As concerns Series No. 14, heterogenous nerve transplants stored in liquid petrolatum, in none of the experiments of longer duration was regeneration of the distal segment of the resected and bridged nerve attained through the heterogenous transplant. The nerve segment was found firmly united to the central and distal nerve stump. On staining after the pyridine-silver method, the stored, heterogenous nerve transplant presented a peculiar reaction toward the silver nitrate in that the silver appeared to be reduced en masse, so that no differentiation of elements was possible within the perineural sheath of the funiculi transplanted. This made a close histologic study of the behavior of the transplanted nerve segments in these experiments difficult and in the main unsatisfactory, in that it could not be determined with certainty whether down-growing neuraxes of central origin passed through the transplant to reach the distal segment of the nerve. Down-growing neuraxes were found in the central nerve bulb and from this could be traced in the general direction of the central end of the nerve transplant, but also into the connective tissue surrounding the transplant and in this connective tissue to the level of the distal wound. In none of the experiments was neurotization of the distal segment attained. In the experiments of Series No. 15, in which heterogenous nerve transplants stored in 50 per cent alcohol were used, the end results attained are much less satisfactory than in the series in which homogenous nerve transplants were used (Series No. 13). The several animals were under observation for from 64 days to 154 days, thus for a time of sufficient length to admit of regeneration through the transplant, under favorable conditions. It may be noted on study of the protocols that to a limited extent downgrowth of central neuraxes through the transplants was observed; our results thus confirming Nageotte.[77] The long persistence of fragments of the neuraxes of the transplanted nerves is to be noted, especially in Experiment No. 224, terminated 152 days after the operation. In the central portion of the transplant near the central wound and for several millimeters distal, quite long fragments of old neuraxes stained differentially by the pyridine-silver method are to be found. Distal to this region they have disappeared from the remains of the transplanted

nerve fibers. Judging from the limited number of experiments here presented (3), testing the value of heterogenous nerve transplants stored in 50 per cent alcohol, it seems clear that this form of nerve bridge is not to be advocated as worthy of consideration in human surgery. The experiments of this series in so far as they can be compared with the series in which homogenous nerve transplants stored in 50 per cent alcohol (Series No. 13) were tested, indicate that there is distinct difference as regards serviceability between homogenous and heterogenous nerve transplants stored in 50 per cent alcohol and in favor of the alcoholized homogenous nerve transplants.

AUTO-NERVE TRANSPLANTS WRAPPED IN PROTECTIVE MATERIAL

SERIES NO. 16

AUTO-NERVE TRANSPLANTS WRAPPED IN CARGILE MEMBRANE

In this and the following several series (Series No. 16, No. 17, No. 18, and No. 19) we have attempted to test the merits of certain membranous structures which had been recommended for use in surgical practice, as a covering for suture lines in operations of nerve suture or as a wrapping about a nerve transplant and the suture lines or in other operative procedures in peripheral nerve repair. Incidental references are found in surgical literature to a number of membranous structures used for wrapping nerves or tendons after operative procedure. Our list of experiments might have been extended had cognizance been given to all of the materials used for this purpose. References to the use of Cargile membrane are not infrequent. It seemed to be used sufficiently frequently to warrant renewed experimental inquiry. Morris [78] states that he had received from Dr. Charles H. Cargile, of Arkansas, "sterilized animal membrane" (dried and sterilized peritoneum of the ox) with the request that he test its use and value in surgical practice, especially as a means of preventing adhesions in certain cases of abdominal surgery. Twelve experiments on rabbits were made. Morris found that the membrane resisted absorption for more than 10 days but less than 30 days when placed in the peritoneal space. Craig and Ellis [79] undertook a series of experiments on dogs using both chromatized and unchromatized Cargile membrane to wrap tendons and also nerves. They reached the conclusion that both the chromatized and the unchromatized membrane are of value in preventing adhesions of wounded nerves and tendons when such structures lie in tissue subjected to trauma. It was their observation that especially unchromatized Cargile membrane is absorbed relatively quickly in the tissues; macroscopically within 5 days, microscopically within 14 days. The membrane appears to be destroyed by a lytic substance contained in the body fluids, phagocytes being regarded as of less importance in this process of disintegration and absorption. Sherren, [80] in several places, refers to the use of Cargile membrane or foil in connection with nerve suture and nerve transplantation. Other writers refer to the use of other animal membranes such as hernial sac, peritoneum, omentum, etc., used as fresh or as dried sterilized membranes. Meuriot and Platon [81] used strips some 20 cm. long and 5 cm. wide, cut from rubber gloves and wrapped spirally

about the nerve, at the seat of injury. This technique was used in 100 cases and in 93 without unfavorable reaction.

In experiments of Series No. 16, the sciatic nerve of a dog was resected to the extent of approximately 4 cm. and the defect bridged by a segment of necessary length removed from the ulnar of the opposite side of the same dog. After the nerve transplant had been completed with the necessary sutures placed, one or several layers of Cargile membrane of sufficient length to extend about 1 cm. beyond the central and distal suture lines were wrapped about the nerve transplant and the ends of the central and distal stumps as closely and as evenly as could be. The Cargile membrane used was that made by Johnston and Johnston and was designated as "medium hard chromic." Pieces of requisite size, either of one layer or of several layers, were cut from pieces found within the several envelopes, as found in the market, and used at once as wrapping for the operated nerve, after which the wound was closed. An attempt was made to sterilize the portion of the Cargile membrane not used at any one operation, until it occurred to us to place the unused portion of any membrane in 70 per cent or 95 per cent alcohol, in which the membrane fragments were kept until further used. Before actual use, the membrane piece to be used was placed in absolute alcohol for several hours or perhaps a day. From the absolute alcohol the membrane was placed, just before use, on a dry, sterile towel so as to enable the absolute alcohol to evaporate. In this dry state, after the evaporation of the alcohol, the membrane was used as a wrapping for an operated nerve. As will be noted on reading the protocols, Cargile membrane thus stored in absolute alcohol reacts very differently toward tissues than Cargile membrane not stored in alcohol. In our discussion we shall use the term "alcoholized Cargile membrane" meaning thereby Cargile membrane, either chromatized or unchromatized, which had for a time been kept in alcohol. The characteristics of an alcoholized Cargile membrane were discovered quite by accident. Our own observations pertain to the use of such a membrane as a wrapping for an operated nerve; its wider application in surgery has not been considered.

The protocols of experiments under Series No. 16, auto-nerve transplants with a wrapping of "Cargile membrane" and "alcoholized Cargile membrane," are as follows:

PROTOCOLS

Experiment No. 226.—Dog No. 34; medium size; full grown; 20 hours. May 28, 1918, left sciatic exposed and internal popliteal freed. Right ulnar exposed. A segment 4.6 cm. length of right ulnar transplanted to the resected internal popliteal; one central and distal fine silk thread suture used; distally a second epineural suture placed. Good approximation attained. A single layer of Cargile membrane, cut long enough to overlap suture lines 5 mm., wrapped about nerve; well applied, forms close-fitting tube. Both wounds closed. May 29, dog found dead next morning; distemper. Wound reopened, and sciatic exposed. Resected nerve ends appear slightly congested. Transplant and Cargile membrane found well in place; a small amount of fluid noted within membrane; membrane loosely adherent to surrounding tissues; adhesions easily broken down. Nerve and transplant surrounded by Cargile membrane removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin.

Microscopic findings.—In cross and longitudinal sections, Cargile membrane presents the appearance of a thin layer of dense collagenous connective tissue. Numerous leucocytes

between membrane and epineural sheath of the transplant. Coagulum and numerous leucocytes on outer surface of membrane. At the central wound, beginning degeneration of distal end of central nerve fibers noted; leucocytes and extravasated red blood cells between these fibers. In central end of transplant, for a distance of about 1 mm., myelin degeneration noted; here leucocytes in and between neurolemma sheaths of fibers. More distal in the transplant, few leucocytes observed.

Experiment No. 227.—Dog No. 33; half grown; medium size; 3 days. May 27, 1918, left sciatic exposed and the internal popliteal freed. Right ulnar exposed and freed. A segment of 5 cm. length of right ulnar transplanted to left internal popliteal. One central and distal silk suture placed. Distal suture gave way; in resuturing this central suture gave way; central resutured. Fair approximation attained. A single layer of Cargile membrane wrapped about transplant and suture lines; well applied. Wounds closed. May 30, dog found dead in the morning; distemper. Superficial wounds healed. On exposing sciatic, slight infection of deep wound noted. The Cargile membrane evident; small amount of exudate within the membrane. Resected nerve and transplant with Cargile membrane removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin.

Microscopic findings.—In sections, Cargile membrane is found well in place. Coagulum, leucocytes, extravasated blood observed within membrane and about its outer surface. Beginning degeneration of distal end of central stump and central end of the transplant to be observed. Central end of transplant and distal end of central stump united; fibrin, coagulum, leucocytes, extravasated red blood cells intervening. Leucocytes observed in and between neurolemma sheaths of the transplanted nerves.

Experiment No. 228.—Dog No. 3; medium size; full grown; 56 days. June 11, 1918, right sciatic exposed and the internal popliteal freed. The left ulnar exposed. A segment 2 cm. length of left ulnar transplanted to the right internal popliteal. One central and distal fine silk thread suture placed; good approximation. Two layers of Cargile membrane wrapped about transplant and the resected nerve ends; well applied, forming close-fitting tube. Slight oozing from resected nerve ends, not controlled. Both wounds closed. August 6, killed. Dog in good condition; active; no neurotrophic ulcer right foot. Wound well healed. On exposing the right sciatic, transplant is found well in place; no trace of Cargile membranes evident. Quite a little increase of connective tissue about the transplant and suture lines noted; adherent to underlying muscles. No distinct central bulb noted. No contraction of the calf muscles on cutting the nerve. Resected nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Differential neuraxis silver staining not entirely satisfactory.

Microscopic findings.—In both cross and longitudinal sections of the region of the transplanted nerve segment no trace of the Cargile membranes observed. Distinct thickening of the epineural sheath of the transplant observed. New neuraxes can be traced from the distal end of the central stump, through the central wound into the transplant, and through the transplant into the central end of the distal popliteal; relatively few neuraxes have passed the distal wound. Remains of degenerated myelin observed in the transplant. Many small myelin ovoids seen in the distal popliteal, as also numerous nucleated syncytial bands in which no neuraxes are differentiated observed.

Experiment No. 229.—Dog No. 30; large; full grown; 129 days. May 22, 1918, two segments of the right ulnar of 2.3 cm. length transplanted to the resected left sciatic. Each segment sutured separately, centrally, and distally, using fine Chinese silk sutures. Fair approximation attained. The transplants and the resected nerve ends, for a distance of 8 mm., wrapped in a single layer of Cargile membrane well applied. Both wounds closed. September 28, dog found dead in the morning. Seemed fairly well day previous; moderate emaciation; skin disease; no neurotrophic changes left foot. On removing skin over operated nerve a small encapsuled stitch abscess noted; does not extend to deeper tissues. On exposing the left sciatic, no material increase of connective tissue noted. Transplants found well in place, demarked by presence of sutures. Transplant presents the appearance of a normal nerve. No trace of Cargile membrane observed. No distinct central bulb noted. Calf muscles of good size and color. Left sciatic and transplant, posterior tibial and external popliteal removed and fixed in ammoniated alcohol for pyridine-silver staining.

Microscopic findings.—No trace of Cargile membrane observed in sections. In cross sections of the transplant about 1 cm. distal to the central wound, the funicular structure of both of the transplanted ulnar segments preserved, and are surrounded by common fibrous tissue sheath. All of the funiculi on the transplanted ulnar segments contain new neuraxes, certain of these are myelinated, the majority not. Numerous small bundles of nerves observed in the connective tissue intervening between the two nerve segments transplanted. Numerous neuraxes can be traced from the transplants through the distal wound into the distal sciatic segment, all of the funiculi containing them. New neuraxes in good number observed in the posterior tibial and the external popliteal.

Experiment No. 230.—Dog No. 2; medium size; full grown; 342 days. June 12, 1918, right sciatic exposed and the internal popliteal bundle freed. The left ulnar exposed and freed. A segment of 2 cm. length of the left ulnar transplanted to the right internal popliteal. One central and one distal fine silk thread suture placed; good approximation. A double layer of Cargile membrane wrapped about transplant and resected nerve ends; well applied. Both wounds closed. May 20, 1919, killed. Dog in very good condition; uses right foot well as normal dog. On exposing the right sciatic, external popliteal bundle found free. Distinct central bulb, which tapers toward the transplant, noted. Transplant has the appearance of normal nerve, though surrounded by quite dense connective tissue and adherent to underlying muscle. No trace of Cargile membrane. Calf muscles exposed; these have the appearance of normal muscle. Nerve and transplant completely freed. On slowly cutting nerve with scissors central to the transplant, vigorous contraction of calf and plantar foot muscles. Nerve and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Neuraxes only very lightly stained.

Microscopic findings.—Numerous myelinated and nonmyelinated nerves traced from central bulbous enlargement to the distal popliteal. In cross sections of the transplant funiculi are found to be well maintained, with only moderate increase of connective tissue about the transplant. Calf and plantar muscle not studied in this experiment.

Experiment No. 231.—Dog No. 35; small dog; full grown; 350 days. June 1, 1918, left sciatic exposed; internal popliteal bundle freed. Right ulnar exposed. A segment 3.4 cm. length taken from the right ulnar and transplanted to the resected left internal popliteal. One central suture of vessel silk; vessel silk suture attempted for distal suture, broken twice; finally Chinese silk suture used. Good central approximation attained, distal "fair." Double layer of Cargile membrane wrapped about transplant and the resected nerve ends; well applied; formed close fitting tube. Both wounds closed. May 16, 1919, killed. Dog in very good condition; active; no neurotrophic changes on left hind foot. On exposing the left sciatic, external popliteal bundle found free. Operated internal popliteal presents appearance of a normal nerve, except that region of the transplanted nerve appears slightly smaller than resected nerve. No trace of Cargile membrane, only very moderate increase of connective tissue about the transplant. Small spindle-shaped central bulb noted. Calf muscles exposed; these have the appearance of normal muscle. External popliteal resected and internal popliteal freed from bed. On cutting nerve slowly with scissors central to the transplant, vigorous contraction of calf and plantar muscles observed. Resected nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Silver differentiation faint.

Microscopic findings.—In longitudinal sections embracing central wound, line of central wound is indistinct. Numerous myelinated and nonmyelinated nerve fibers can be traced from central stump through the transplant to the distal nerve. In cross sections made about middle of the transplant, many myelinated and nonmyelinated fibers observed within the transplant, the funiculi of which are well maintained. Outside of perineural sheath, but within the denser connective tissue surrounding the transplant, many small funiculi of nerve fibers observed. Many new nerve fibers, both myelinated and nonmyelinated, noted in the distal popliteal. No trace of Cargile membrane observed in any of the sections.

Experiment No. 232.—Dog No. 32; medium size dog; full grown; 358 days. May 24, 1918, left sciatic exposed; internal popliteal freed. Right ulnar exposed and freed. A segment of 3 cm. length taken from the right ulnar transplanted to the left internal popliteal. Three epineural sutures placed distally; good approximation. A single layer of Cargile

membrane wrapped about transplant and resected nerve ends; well applied. Both wounds closed. May 19, 1919, killed. Dog in very good condition; walks well. No neurotrophic changes left hind foot. On exposing the left sciatic external popliteal found free. Operated internal popliteal presents a small spindle-shaped central bulb; otherwise the appearance of a normal nerve. No trace of Cargile membrane. No material increase of connective tissue about the transplant noted. Calf muscles exposed; these of normal size and appearance. The internal popliteal and transplant freed from the bed. On slowly cutting the nerve with scissors central to the transplant, good contraction of the calf and plantar muscles observed. Nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good differential silver staining attained.

Microscopic findings.—In longitudinal sections of the central wound region, the central wound not easily located. Numerous myelinated and nonmyelinated nerves pass from distal end of the central bulb to and through the transplant to the distal nerve. In cross sections of the transplant taken near the central wound, many new nerve fibers found within the transplant. Funiculi and perineural sheaths maintained. Many small nerve funiculi in the connective tissue surrounding the transplant. In cross sections through the distal part of the transplant, perineural sheaths of transplant not so distinct. Numerous smaller and larger funiculi in the connective tissue outside of the transplant, in distribution more or less clearly bounded by an outer fairly dense connective tissue sheath, probably connective tissue replacing the Cargile membrane. Many new nerve fibers, nearly as many as seen in a normal nerve, traced through the distal wound into the distal popliteal. Very complete regeneration through the transplanted nerve segment.

Experiment No. 233.—Dog No. 31; large; full grown; 359 days. May 23, 1918, left sciatic exposed and freed. Right ulnar exposed and freed. A segment of 2.9 cm. length taken from the right ulnar transplanted to the left sciatic. One central and distal fine silk thread suture placed; fairly good approximation attained. One layer of Cargile membrane wrapped about the transplant and resected nerve ends; well applied, forming closely fitting tube. Both wounds closed. May 19, 1919, killed. Dog very good condition; uses left hind leg well; no neurotrophic changes left hind foot. On exposing the left sciatic, the region of the nerve transplant is located by reason of the distinct central bulbous enlargement. Transplant has the appearance of a normal nerve; no material increase of connective tissue about it. No trace of Cargile membrane. Calf muscles exposed; these have the appearance of normal muscle. After freeing nerve and transplant from the bed, on slowly cutting nerve central to transplant, vigorous contraction of calf and the plantar foot muscle noted. Sciatic and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—In longitudinal sections through the central wound, central bulb distinctly evidenced by crisscrossing and tangling of the neuraxes of this region; line of central wound not clearly demarked. Numerous neuraxes pass from central bulb to and through the transplant. In cross sections of the transplanted nerve funicular structure and sheaths clearly are maintained. Numerous new nerve fibers observed with the transplant. Nearly all of the neuraxes observed in cross sections of the transplant found within its sheaths; only a few small scattered nerve funiculi found in the connective tissue surrounding the transplant. Numerous nerve fibers, myelinated and nonmyelinated, can be traced to the distal sciatic in which they are found in all of its several funiculi about equally distributed.

Experiment No. 234.—Dog No. 30; large; full grown; 44 days. August 15, 1918, right sciatic exposed and internal popliteal bundle freed. Left ulnar exposed and freed. A segment 2.1 cm. length taken from the left ulnar transplanted to the right internal popliteal. One central and one distal waxed, fine silk thread suture placed; good approximation. Two layers of Cargile membrane which had been stored several days in 70 per cent alcohol, then for 24 hours in absolute alcohol and before use spread on a dry, sterile towel until dry, wrapped about the nerve and the resected nerve ends. (Cargile membrane thus treated is in subsequent experiments referred to as alcoholized Cargile membrane.) Cargile membrane well applied; close-fitting tube formed. Both wounds closed. September 28, dog found dead in the morning; seemed fairly well the day before; skin disease; moderate emaciation. Wound well healed. On exposing the right sciatic, external popliteal found free. Region of the

transplant in the internal popliteal easily located by reason of the presence of the Cargile membrane, which appeared wrapped about the nerve, forming a closely fitting sheath which was only slightly adherent to the surrounding connective tissue. It seemed evident that there had taken place no absorption of the alcoholized Cargile membrane. Nerve and the transplant with the Cargile membrane removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; hematoxylin and eosin; safranine and licht grün.

Microscopic findings.—Alcoholized Cargile membrane evident in all of the sections, cross and longitudinal, taken at different levels in the transplant and through central and distal wounds. In cross sections of the transplant, the two layers of the membrane appear as undulating membranes of fibrous tissue, which show no evidence of undergoing absorption. On both faces of the membranes newly formed, vascularized connective tissue observed. Cargile membranes found to overlap central and distal wounds for a distance of 6 mm. to 8 mm. The transplanted nerve segment found well united to resected nerve ends. In cross sections of the transplant, it may be observed that the funicular arrangement is well maintained, as also the perineural sheath of the funiculi. Between these perineural sheaths

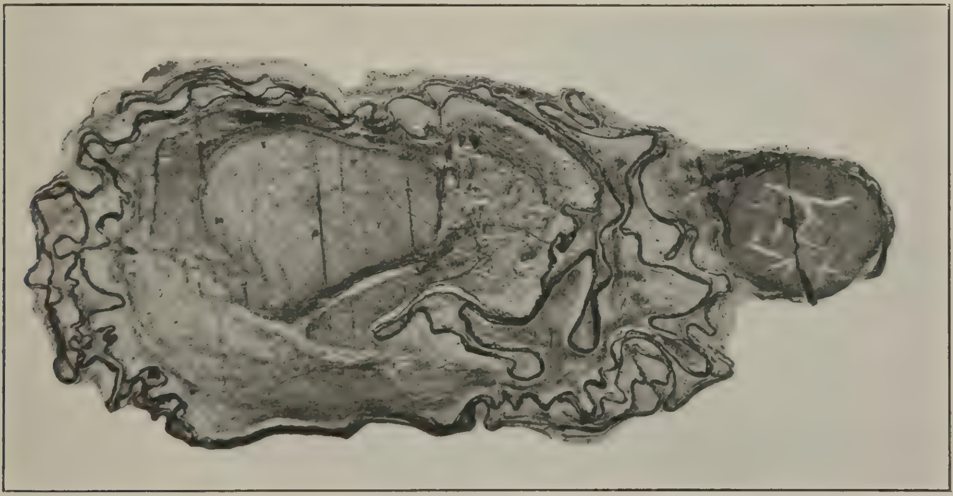

FIG. 233.—Cross section of auto-nerve transplant, wrapped with two layers of alcoholized Cargile membrane, Experiment No. 234, 44 days after operation. Tissue fixed in formalin and stained in iron-hematoxylin. The deeply stained and folded lines in the figure represent sections of the Cargile membrane. Note the absence of marked connective tissue proliferation

and the Cargile membrane newly formed connective tissue is found. In this connective tissue numerous small nerve funiculi observed; these are limited in distribution peripherally by the Cargile membrane.

EXPERIMENT No. 235.—Dog No. 56; large; full grown; 172 days. July 24, 1918, left sciatic exposed; internal popliteal bundle freed. The right ulnar exposed and freed. A segment of 4 cm. length taken from the right ulnar transplanted to the left internal popliteal. One central and distal waxed, fine silk thread suture placed. Central approximation good; distal fair, improved by epineural suture. Transplant and the resected nerve ends wrapped in two layers of alcoholized Cargile membrane; well applied, forming closely fitting tube. Adrenalin used to control oozing; dry, clean field. Both wounds closed. January 11, 1919, dog had been very active. Found dead in the morning, having hung himself on a tie rope. No neurotrophic changes left hind foot. On exposing the left sciatic external popliteal found free; only very loosely adherent to operated internal popliteal. Operated internal popliteal appears of relatively large size. Closer inspection reveals that the alcoholized Cargile membrane had not been absorbed, and is surrounded by a thin layer of connective tissue only loosely adherent to the surrounding tissue. No distinct central bulb evident,

Cargile membrane extending over central suture. Calf muscles exposed; these present the appearance of normal muscles. The whole of the sciatic nerve, with transplant and the Cargile membrane sheath removed in one piece and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining, though pale, attained.

Microscopic findings.—In all of the several series of sections, though especially in cross sections of the transplant, the two layers of the Cargile membrane distinctly observed, surrounded by a thin layer of fairly dense connective tissue. The membranes have the structural appearance of closely felted fibrous tissue, though silver stain used does not differentiate this tissue clearly. The funiculi of the transplanted nerve segment evident. Numerous myelinated and nonmyelinated nerve fibers observed within the transplant. Between the denser connective tissue enveloping the Cargile membrane and the perineural sheaths, a looser connective tissue observed; in this, here and there, groups of fat cells seen. In this looser connective tissue, smaller and larger nerve funiculi seen. Regenerating nerve fibers traced through the distal wound into the distal popliteal nerve, in which there may be observed, in all of the funiculi, numerous myelinated and nonmyelinated nerve fibers.

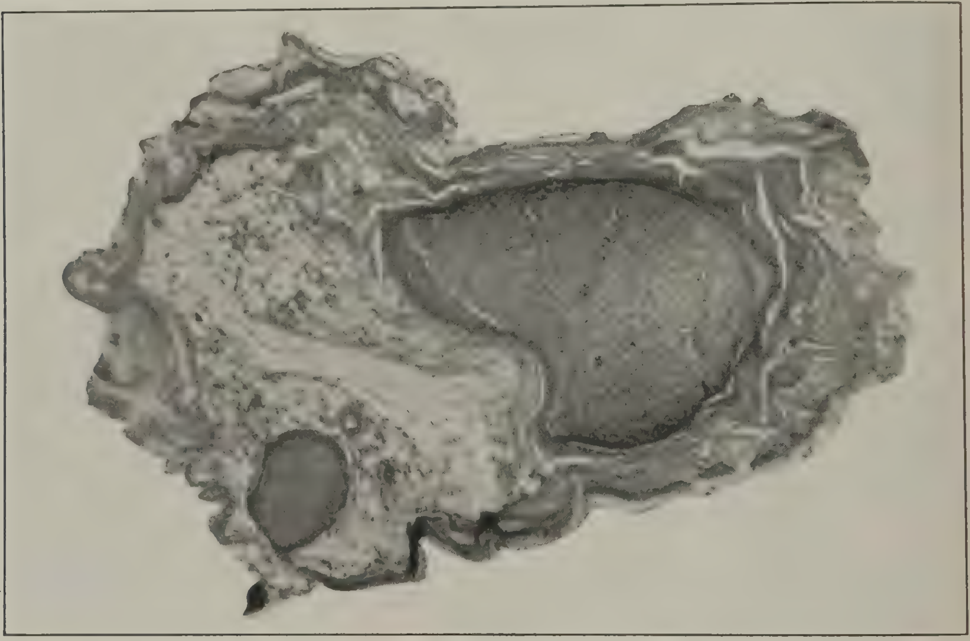

Fig. 234.—Cross section of auto-nerve transplant, wrapped in alcoholized Cargile membrane, Experiment No. 236, terminated 272 days after the operation; pyridine-silver preparation. The Cargile membrane as a wavy, undulating layer embedded in the fibrous tissue surrounding the nerve trunk. Note the neurotization of the transplanted nerve segment as seen in the figure

Experiment No. 236.—Dog No. 35; small dog; full grown; 272 days. August 20, 1918, right sciatic exposed and the internal popliteal bundle freed. Left ulnar exposed and freed. A segment of 3 cm. length taken from the left ulnar transplanted to the right internal popliteal. One central and distal waxed, fine silk thread suture placed. Only fair central and distal approximation attained. One layer of alcoholized Cargile membrane wrapped about transplant and the resected nerve ends; fairly smooth tube formed. Both wounds closed. May 19, 1919, killed. Dog in very good condition. No neurotrophic changes right hind foot. On exposing the right sciatic, external popliteal found free. Quite distinct central bulb on internal popliteal noted. Macroscopically, no trace of Cargile membrane. Moderate increase of connective tissue about operated internal popliteal in region of the transplant recorded. Calf muscles exposed; these have the appearance and size of normal muscles. After freeing operated internal popliteal and transplant and cutting the external popliteal

near head of fibula, on slowly cutting with scissors the nerve central to the transplant, good contraction of calf and foot muscles observed. Sciatic and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good differential silver staining attained.

Microscopic findings.—In longitudinal sections of the central wound, distinct central bulb, evidenced by twisting and intercrossing of neuraxes, noted. Numerous myelinated and nonmyelinated nerve fibers enter the transplant. In cross sections of the transplant 1 cm. distal to the central wound, evidence of the Cargile membrane made out in the form of a wavy, undulating membrane of fibrous tissue enveloped in a fairly dense layer of fibrous tissue. This not so clearly observed in longitudinal sections of the transplant. The funiculi of the transplanted nerve segment clearly demarked; many new nerve fibers observed within these funiculi; both myelinated and nonmyelinated. A looser connective tissue intervenes between the perineural sheaths and the peripheral denser layer of the fibrous tissue enveloping the Cargile membrane. In this a few small nerve funiculi observed. Numerous myelinated and nonmyelinated nerve fibers observed in the distal popliteal in all of its nerve funiculi.

Experiment No. 237.—Dog No. 32; medium size; full grown; 274 days. August 17, 1918, right sciatic exposed and the internal popliteal bundle freed. The left ulnar exposed and freed. A segment of 2.1 cm. length taken from the left ulnar transplanted to the resected right internal popliteal. One central and distal waxed, fine silk thread suture placed. "Fair" central and distal approximation attained. Two layers of alcoholized Cargile membrane wrapped about the transplant and resected nerve ends; good tube formed distally, not so good centrally. Both wounds closed. May 19, 1919, killed. Dog in very good condition; uses right hind foot well; no neurotrophic changes right hind foot. On exposing the right sciatic, external popliteal bundle found free. Moderate increase of connective tissue about operated internal popliteal in region of the transplant. No macroscopic evidence of Cargile membrane. Calf muscles exposed; these have the size and appearance of normal muscles. After cutting the external popliteal near head of fibula and completely freeing the sciatic and the transplant from the bed, on slowly cutting with scissors the nerve central to the transplant, good contraction of calf and foot muscles observed. Sciatic and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining in only part of the series; the remainder pale.

Microscopic findings.—In cross sections of the transplanted nerve segment made about 1 cm. distal to the central wound, there is observed a dense fibrous tissue layer separated from the epineural and perineural sheaths of the transplant by looser connective tissue. This outer, denser layer of connective tissue may contain remnants of the Cargile membrane; if so, these are not clearly differentiated in the silver stain. Numerous myelinated and nonmyelinated nerve fibers within the funiculi of the transplanted nerve segment observed; as also in the connective tissue surrounding the transplant. Numerous myelinated and nonmyelinated nerve fibers can be traced through the transplant and distal wound to the distal popliteal.

Experiment No. 238.—Dog No. 31; large; full grown; 275 days. August 16, 1918, right sciatic exposed; internal popliteal bundle freed. The left ulnar exposed and freed. A segment of 3.6 cm. length taken from the left ulnar transplanted to the resected right internal popliteal. Quite a little bleeding; controlled. One central and distal waxed, fine silk thread suture placed; good approximation. Two layers of alcoholized Cargile membrane wrapped about the transplant and resected nerve ends; well applied, forming close-fitting tubular sheath. Both wounds closed. May 19, 1919, killed. Dog in very good condition; used right hind foot well; no neurotrophic changes right foot. On exposing the right sciatic, external popliteal found free. Only moderate increase of connective tissue about operated internal popliteal, especially transplant region, observed; here somewhat adherent to underlying muscle. No macroscopic evidence of Cargile membrane noted. Small spindle-shaped central bulb found. Calf muscles exposed; these have the appearance and size of normal muscles. Nerve and transplant freed from bed. On slowly cutting with scissors nerve central to the transplant, contraction of calf muscles and movement of toes observed. The nerve and the transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Fair differential silver staining attained.

Microscopic findings.—In longitudinal sections of the central wound area, central bulb is evidenced structurally by twisting and crisscrossing of neuraxes. In cross sections of the transplant, it is observed that the funicular structure of the nerve is well maintained; each funiculus with its perineural sheath. Numerous myelinated and nonmyelinated nerve fibers observed within these sheaths. A relatively dense layer of fibrous tissue surrounds the transplant; in this layer no distinct evidence of the Cargile membrane noted, except near distal wound; here, in a series of longitudinal sections, remnants of Cargile membrane seen. A layer of looser connective tissue intervenes between the perineural sheaths and the peripheral layer of denser fibrous tissue; in this looser fibrous layer many small funiculi of nerve fibers observed. Numerous myelinated and nonmyelinated nerve fibers can be traced through the distal wound into the distal popliteal nerve.

Experiment No. 239.—Dog No. 52; medium size; full grown; 300 days. July 19, 1918, left sciatic exposed; internal popliteal freed. Right ulnar exposed and freed. A segment of the right ulnar of 3.8 cm. length transplanted to the resected left internal popliteal. One central and distal waxed, fine silk thread suture placed; very good central and distal approximation. Four layers of alcoholized Cargile membrane wrapped about the transplant and the resected nerve ends. Wound not quite dry; a small amount of blood with Cargile membrane sheath, especially near distal suture. Both wounds closed. May 15, 1919, killed. Dog in very good condition; uses left hind foot well; no neurotrophic changes. On exposing the left sciatic, it is observed that the external popliteal is moderately adherent to the operated internal popliteal, especially near distal wound. Moderate increase of connective tissue about the transplant. Transplant appears relatively thick in its middle third; it could not be determined on gross inspection whether a portion of the Cargile membrane sheath had not been absorbed. Calf muscles exposed; these have appearance and size of normal muscles. Nerve and transplant completely freed from bed. Observer was unavoidably interrupted and could not test the functional return of muscles until about one-half hour after dog was killed. Cutting the nerve central to transplant causes only very feeble contraction of the calf muscles; no toe movement noted. Nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining central portions, distal only fair.

Microscopic findings.—In longitudinal sections of the central wound area, evidence of central bulb observed, this evidenced by the twisting and crisscrossing of neuraxes in region of central wound and central stump proximal thereto. Many nerve fibers traced to the central end of the transplant. In cross sections of the transplant taken about 1 cm. distal to the central wound, the appearance presented suggests the possibility that two nerve segments were transplanted (ulnar and median or ulnar and musculo-cutaneous) in that two relatively large nerves, distinctly separated and surrounded by a relatively dense layer of connective tissue, are observed. No distinct evidence of the Cargile membrane sheath noted in this denser fibrous layer. Between the perineural sheaths of the nerve transplant and the peripheral denser fibrous sheath a looser connective tissue intervenes; in this are found numerous small nerve funiculi. Numerous myelinated and nonmyelinated nerve fibers can be traced through the transplant and distal wound into the distal popliteal, in which they are found in large numbers.

Our experimental observations relating to the use of Cargile membranes as a wrapping for operated or liberated peripheral nerves confirms the observations of Craig and Ellis[79] in so far as concerns the early absorption of both the unchromatized and the chromatized Cargile membrane such as is furnished commercially for use in surgical practice. A number of our experiments are not here listed owing to the death of animals from intercurrent infectious disease. A number were of relatively short duration and permitted observation as to the early disappearance of the Cargile membrane, when placed in tissue. In a number of discarded experiments there was wound infection. Taking into consideration these experiments not listed it is our observation that Cargile membrane when wrapped about a peripheral nerve and inclosed

within an aseptic wound disintegrates and is absorbed within 10 days to 15 days. Experiments No. 226 and No. 227 may serve to show that a Cargile membrane when wrapped about a nerve incites relatively little connective-tissue proliferation. Leucocytes are evident in the tissue fluids within and outside of the membrane. By the middle of the second month after the operation (Experiment No. 228) there could be found no trace of the two layers of the Cargile membrane used in this transplant. It is especially during the first two months after the operation of peripheral nerve suture or of nerve transplantation that a membranous structure wrapped about a nerve would be most effective in preventing ingrowth of connective tissue and prevent the spread of down-growing neuraxes. Downgrowth of central neuraxes is not pronounced until toward the end of the second week, although evident prior to this time. Cargile membrane as found in trade, therefore, can not exert much influence one way or the other when used as a wrapping about an operated peripheral nerve. Four of the experiments (No. 230 to No. 233) were carried on respectively for nearly a year. In these experiments there was found quite complete repair of the peripheral nerve through the transplant, and, as the records show, not very much increase of connective tissue in the region of the transplant. The increase in the connective tissue noted is evident in an increase in the density of the epineural sheath as also in the formation of a layer of fibrous tissue which appears to have replaced the Cargile membrane.

The results attained in the experiments in which "alcoholized Cargile membrane" was used were wholly unexpected. The method of storing unused portions of Cargile membrane in alcohol was resorted to as a ready means for keeping sterile portions of the membrane not used at any one experiment. Much surprise was experienced on exposing the operated nerve in Experiment No. 234, 44 days after the operation, to find the region of the operation completely surrounded by a layer of Cargile membrane, which, like the nerve itself, above and below the seat of the operation was only very loosely attached to the surrounding tissue. It had been anticipated in this experiment that no trace of the Cargile membrane would be found. On consulting the records it was found that the Cargile membrane used in this case had been stored in alcohol prior to use in the operation. In Experiment No. 234, which terminated approximately one and one-half months after operation, the two layers of Cargile membrane wrapped about the nerve at the time of operation appear not to have been affected by the tissue fluids nor by phagocytic action. The two layers of Cargile membrane and the nerve funiculi of the transplanted nerve segment are occupied by cellular, loose connective tissue. In the connective tissue are found small bundles of neuraxes, confined within the Cargile membrane. To what extent the presence of the alcoholized Cargile membrane would operate to prevent the ingrowth of connective tissue can only be conjectured. It should be borne in mind that the connective tissue found in the regions of the central and distal wounds in the early stages of nerve repair after resection and bridging by a nerve transplant, or in the one wound after simple suture, is histogenetically to a large extent derived from the connective tissue of the severed nerve trunk, its endo-, peri-, and epi-neurium. Even after the most favorable primary nerve suture, in aseptic tissue, with desired

approximation of severed nerve ends, embryonic connective tissue which progresses toward the stage of connective tissue fibril formation is formed between the severed nerve ends. Slight hemorrhage with formation of blood clot increases the connective tissue formation in proportion to clot formation. Wrapping with Cargile or other membranous structures does not prevent this. The connective tissue found between the central stump of a resected nerve and the central end of a nerve transplant, at the time when the central neuraxes begin to grow toward the periphery during the first 10 days to 14 days after the operation, is not materially influenced by the presence or absence of an alcoholized Cargile membrane. In an operation for nerve transplantation in which a nerve segment of perhaps 6 cm. to 8 cm. in length is used as a nerve bridge the central neuraxes would not reach the region of the distal wound until after the expiration of from 8 weeks to 12 weeks after the operation, at which time the connective tissue at the distal wound would be quite fully organized. There seems warrant for the statement that in the distal wound region the presence of the alcoholized Cargile membrane would influence the ingrowth and differentiation of the connective tissue. In Experiment No. 235, terminated somewhat over five months after the operation, the two layers of alcoholized Cargile membrane used at the operation were still evident macroscopically at the time the nerve was exposed and removed for study. The Cargile membrane was found surrounded by a thin layer of connective tissue only loosely adherent to the surrounding tissue. Between the Cargile membrane and the perineural sheaths of the funiculi of the nerve transplant, there is found a loose areolar tissue containing here and there fat cells arranged in small groups or singly. Denser areolar connective tissue surrounds the external surface of the Cargile membrane. In this experiment the small bundles of neuraxes found outside of the perineural sheaths of the nerve transplant are noted in the loose areolar tissue observed within the Cargile membrane. In experiments terminated approximately nine months after the operation (Experiments No. 236 to No. 239) in which alcoholized Cargile membrane was used to wrap the nerve in the field of operation, either as single layer or as several layers, the Cargile membrane was not recognized macroscopically at the time the nerves were removed for study nor with any degree of certainty microscopically in sections. A layer of relatively dense fibrous tissue, in the form of wavy, undulating, fibrous bands, more readily recognized in cross sections of the transplant region, appear to have replaced the Cargile membrane. Within this layer there is an area of looser areolar tissue with groups of fat cells, separating the denser layer from the transplanted nerve trunk. In each of the four experiments of relatively long duration it is worthy of note that the funicular structure of the transplanted nerve segments was well maintained; neurotization of the distal segment of the operated nerve had been obtained through down growth of central neuraxes, which pass in the main through the funiculi of the transplanted nerve segments.

The experiments in which alcoholized Cargile membrane was used as a sheath for the operated nerve in the field of nerve repair seem to us to warrant the deduction that Cargile membrane stored in alcohol after the manner here

detailed remains unabsorbed when inclosed in aseptic wounds for a period extending at least four months. Alcoholized Cargile membrane was not found to incite unduly connective tissue proliferation; it remains closely adherent to the nerve transplant and the resected nerve ends and does retain within the limits of the membrane the down-growing neuraxes. The presence of the alcoholized Cargile membrane does not appear to influence the downgrowth of the central neuraxes through the funiculi of the nerve transplant. Our experiments seem to us to warrant the conclusion that the use of alcoholized Cargile membrane, prepared as above stated, and used in double or triple layers as a sheath for wrapping nerve trunks at the suture line after the nerve suture or as a wrapping for a nerve transplant when such sheathing is deemed necessary, deserves consideration in operations for peripheral nerve repair.

SERIES NO. 17

AUTO-NERVE TRANSPLANTS, WRAPPED IN AUTO-FASCIAL SHEATHS OF FASCIA LATA

In a series of auto-nerve transplants, the transplant and the central and distal wound regions were insheathed with a layer of fascia lata, taken at the time of operation from the same animal. In these experimental operations the sciatic nerve of a dog was resected and bridged by a nerve transplant taken from the ulnar of the opposite side of the same dog. After thus bridging a nerve defect, the fascia lata on the side on which the sciatic nerve was operated upon was exposed through a long incision, denuded of its subcutaneous covering and a piece 5 cm. to 6 cm. long and 2 cm. wide excised, rinsed in warm sterile salt solution and applied as a sheath inclosing the nerve transplant and the central and distal wounds. A close-fitting tube was formed by placing central and distal stay sutures and intervening half mattress sutures. The inner surface of the fascia lata was placed adjacent the nerve. The operation was somewhat tedious and necessitated the making of three rather extensive surface wounds. The three wounds were closed and, in the majority of the experiments, healed by primary union. Auto-fascial sheaths have been quite extensively used in surgery otherwise than in connection with peripheral nerve repair. Denk [82] used fascia lata tubulization in connection with cases of neurolysis in the Balkan Wars. The cases are not discussed and the value of the fascial sheaths is not clearly brought out. Döpfner [83] and Hirschel [84] advocate the use of fascial sheaths in nerve repair. Kredel [85] had opportunity to reoperate a case 24 days after a fascial sheath was placed about the tibialis which had been liberated and longitudinally incised. It was found that the fascial sheath which had been loosely applied had contracted so as to fit the nerve closely. He expresses the fear that a fascial sheath may contract so as to strangulate the nerve. Kirk and Lewis [86] present a series of experimental observations in which fascial sheaths were used to form a tubular suture. It was found that neuraxes of central origin would pass through the lumen of the fascial tube to reach the distal segment. Their experiments conceived for a different purpose are comparable in so far as concerns the behavior of a fascial sheath in relation with a wounded peripheral nerve.

The protocols of experiments on auto-fascial sheaths for auto-nerve transplants are as follows:

PROTOCOLS

Experiment No. 240.—Dog No. 18; large; full grown; 14 days. May 15, 1918, left sciatic exposed and freed. Right ulnar exposed and freed. Two segments of the right ulnar, each having 3 cm. length, transplanted to the resected left sciatic. For each segment, one central and distal suture of fine Chinese silk placed; good central, "fair" distal approxima-

Fig. 235.—Cross section of an auto-nerve transplant, wrapped in an auto-fascial sheath, Experiment No. 240, terminated 14 days after operation; formalin fixation iron-hæmatoxylin staining. Note the funicular structure of the two ulnar nerves used as transplants. The tube of fascia is clearly evident in the figure. Epineural fibrous tissue is materially increased

tion attained. The fascia lata of the left leg exposed and a piece 4.5 cm. long and 2 cm. wide exsected and wrapped about the nerve transplants and resected nerve ends, with the inner surface of the fascia lata adjacent to the nerve. Central and distal stay sutures of Chinese silk and two intervening half mattress sutures placed, forming a fascial tube. The three wounds closed. May 29, dog found dead in the morning. The fascial and ulnar wounds open. Sciatic wound, deep wound healed, superficial wound several stitches have given away. On exposing the left sciatic, fascial sheath found well in place; surrounded by newly

formed connective tissue; adherent to the surrounding tissue and the underlying muscle. Fascial sheath presents a glistening white appearance. Deep wound not congested; no distinct evidence of infection noted. Sciatic and transplant and fascial sheath removed and fixed in neutral formalin. Serial sections stained in iron-hematoxylin and picro-fuchsin.

Microscopic findings.—In longitudinal sections of the central and distal wound areas, it is noted that the distal end of the central stump and the central end of the distal stump present early degenerative changes of the nerve fibers. In cross sections of the transplant and the fascial sheath, the outer surface of the fascial sheath is seen to be covered with coagulum, extravasated red blood cells, numerous leucocytes and newly formed connective tissue. The cross cut transplanted nerves are clearly demarked; their perineural sheaths appear as thickened. Between the inner surface of the fascial sheath and the nerve transplants, newly formed connective tissue, containing many leucocytes and phagocytic cells,

FIG. 236.—Cross section of auto-nerve transplant wrapped in auto-fascial sheath, Experiment No. 241, terminated 15 days after operation; formalin fixation, iron-hæmatoxylin staining. The very complete auto-fascial tube formed is evident in the section. Connective tissue proliferation is clearly recognized but is not excessive

observed. The nerve fibers of the nerve transplant do not present the same type of degeneration as do the nerve fibers of the distal sciatic; fragmentation of the myelin not so far advanced.

EXPERIMENT No. 241.—Dog No. 17; medium size; full grown; 15 days. August 13, 1918, right sciatic exposed and freed. Left ulnar exposed and freed. A segment of 3.6 cm. length taken from the left ulnar transplanted to the resected sciatic. One central and distal waxed, fine silk thread suture placed; good approximation. A portion of the fascia lata taken from the right leg of the same dog wrapped about the transplant and resected nerve ends. Three half mattress sutures placed. Good fascial tube formed. The three wounds closed. August 28, killed. Dog not well since operation. All three wounds in part open; superficial skin wounds, deep wounds healed. On exposing the right sciatic, deep wound found healed; appears not to be infected. Fascial sheath and transplant found well in place. Fascial sheath surrounded by newly formed connective tissue; adherent to surrounding tissue; evidence of sanguineous fluid within the fascial sheath. Sciatic and trans-

plant and fascial sheath removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In cross sections of the transplant and the fascial sheath, transplanted nerve found clearly demarked, its perineural sheaths appear thickened. On both surfaces of the fascial sheath newly formed connective tissue, containing leucocytes, extravasated red blood cells, and coagulum. The tendon cells of the transplanted fascial sheath present normal shape and staining reaction.

EXPERIMENT No. 242.—Dog No. 40; medium size; not quite full grown; 22 days. August 19, 1918, right sciatic exposed and internal popliteal freed. Left ulnar exposed and freed. A segment of 3 cm. length taken from the left ulnar transplanted to the right internal popliteal. One central and distal waxed, fine silk thread suture placed; approximation not good. Central and distal epineural suture improves approximation. An auto-fascial sheath taken from the right fascia lata of the same dog, wrapped about the transplant and resected nerve ends. One central and distal stay sutures and three intervening half mattress silk sutures placed. Good fascial tube formed. The three wounds closed. September 10, killed. Much emaciated; severe skin disease; trophic ulcer over right hip. Sciatic wound not completely healed, several stitches had given away; deep wound seemed healed. On exposing the right sciatic, slight evidence of infection of deep wound noted; parts congested. Transplant and fascial sheath found well in place, surrounded by connective tissue and adherent to underlying muscle. External popliteal found adherent to side of fascial sheath. Sciatic, transplant, and fascial sheath removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In cross sections of the transplant and fascial sheath, fascial sheath found surrounded by newly formed connective tissues containing numerous leucocytes. Between transplanted nerve and fascial sheath newly formed connective tissue, numerous leucocytes, and extravasated blood cells observed. In longitudinal sections of the central and distal wound areas, leucocytes and phagocytic cells especially numerous in the region of central and distal wounds. Distal nerve in process of degeneration. Fragmentation of myelin and breaking down of the nerve fibers of the transplanted nerves not of the same nature as in distal popliteal; proliferation of sheath cells not noted.

EXPERIMENT No. 243.—Dog No. 57; small dog; full grown; 46 days. July 25, 1918, left sciatic exposed; internal popliteal freed. Right ulnar exposed and freed. A segment 3.2 cm. length taken from the right ulnar transplanted to the resected left internal popliteal. Centrally one through-and-through suture and one epineural suture, distally one suture of waxed, fine silk thread placed; approximation good. Adrenalin used; dry field. Fascial sheath taken from the fascia lata of the left leg of the same dog wrapped about transplant and resected nerve ends. Central and distal stay sutures and three intervening half mattress sutures placed. Good, even fascial tube formed. The three wounds closed. Toward the end of July developed skin disease; had not been well some weeks. September 9, the dog found dead in the morning. On exposing the left sciatic, external popliteal found free. Moderate increase of connective tissue about sheath. Distinct central bulb showing through central end of the fascial tube. Sciatic, transplant, and fascial sheath removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In cross sections through the transplant and the fascial sheath there is noted a fairly dense layer of fibrous tissue surrounding the fascial sheath. Sheath in close relation to perineural sheath of transplanted nerve segment, very little connective tissue intervening. Neurolemma sheaths of transplanted nerve segment evident; appear thickened. Certain ones contain ovoids of myelin and phagocytes filled with lipoid granules; others contain syncytial protoplasmic bands; these also observed outside of neurolemma sheaths. Distinct central bulb evidenced structurally. Fascial sheath extends over the central bulb.

EXPERIMENT No. 244.—Dog No. 55; large, full grown; 47 days. July 22, 1918, left sciatic exposed and the internal popliteal freed. The right ulnar exposed and freed. A segment of 3 cm. length taken from the right ulnar transplanted to the left internal popliteal. One central and distal waxed, fine silk thread suture placed; fairly good approximation

attained. A fascial sheath taken from the facsia lata of the left leg of the same dog wrapped about the transplant and resected nerve ends. One central and distal stay sutures and two intervening half mattress sutures placed. Good tube formed. Dry field. The three wounds closed. September 8, dog found dead in the morning; much emaciated; skin disease. On exposing the left sciatic external popliteal found moderately adherent to the operated internal popliteal; easily dissected. Fascial sheath found well in place, distinct increase of connective tissue about it; adherent to underlying muscle. Distal internal popliteal presents a distinct, light-yellow color. Nerve and transplant and the facial sheath removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In cross sections of transplanted nerve and sheath, it is observed that a relatively thick layer of fibrous tissue surrounds fascial sheath. Between the fascial sheath and the transplanted nerve, and blending with the perineural sheath of the same, distinct layer of fairly dense fibrous tissue. In longitudinal sections embracing central and distal wounds, numerous leucocytes observed within the fascial sheath. In cross sections of the nerve transplant, increase in the amount of endoneural connective tissue noted. Within the old neurolemma sheaths, in many instances, one, two, three, or four small medullated fibers observed; other neurolemma sheaths distended with detritus derived from breaking down nerve fibers. Numerous nucleated, syncytial protoplasmic strands noted within the transplant in longitudinal sections of the same.

Experiment No. 245.—Dog No. 38; medium size; full grown; 61 days. June 21, 1918, left sciatic exposed; internal popliteal freed. The right ulnar exposed and freed. A segment of 2.5 cm. length taken from the right ulnar transplanted to the left internal popliteal. One central and distal waxed, fine silk thread suture placed; good approximation. Fascial sheath taken from the fascia lata of the left leg of the same dog wrapped about the transplant and resected nerve ends. One central and distal stay suture and one half mattress suture placed. Adrenalin used to control oozing. The three wounds closed. August 22, dog used in the morning for another operation; found dead 1.30 p. m.; did not recover from second operation. Dog in good condition; slight toe-drop left hind foot; neurotrophic ulcer dorsum of left foot. Sciatic and other wounds well healed. On exposing the left sciatic, the external popliteal found firmly adherent to the fascial sheath about operated internal popliteal. Fascial sheath clearly demarked; marked increase of connective tissue about it. Distinct central bulb evident through proximal end of the fascial sheath. Calf muscles found very atrophic. Nerve and the fascial sheath removed and fixed in ammoniated alcohol for pyridine-silver staining. Quite good differential silver staining attained.

Microscopic findings.—In cross sections of the transplant and the fascial sheath, sheath found in close relation to the transplanted nerve segment; a thin layer of fibrous tissue surrounds the sheath. Endoneural connective tissue of the transplant distinctly increased. New neuraxes, which in longitudinal sections of the central wound can be traced from the distal end of the bulbous enlargment into the transplant, in cross sections are found arranged in the form of numerous very small nerve funiculi, often containing only a few nerve fibers, and without special fibrous sheath, but separated by endoneural connective tissue. New neuraxes traced through the transplant and through distal wound into the distal stump. In cross sections of the distal popliteal, scattered neuraxes found in all of its funiculi, in many instances more than one in old neurolemma sheath. Beginning regeneration of distal popliteal through transplant attained.

Experiment No. 246.—Dog No. 41; small dog; full grown; 31 days. July 28, 1918, left sciatic exposed; internal popliteal freed. Right ulnar exposed and freed. A segment of the right ulnar of 3.5 cm. length transplanted to the resected left internal popliteal. One central and distal waxed, fine silk thread suture placed. Good central approximation; distal partly pulled out as the sheath was being applied, a fascial sheath taken from the left fascia lata of the same dog wrapped about the transplant and resected nerve ends. One central and distal stay suture and one half mattress suture applied. Good fascial tube formed. Wounds clean and dry. All three wounds closed. August 28, dog found dead in the morning; had not been well for some time; much emaciated; small neurotrophic

ulcer on dorsum of left foot. On exposing the left sciatic, external popliteal found quite adherent to fascial sheath. Fascial sheath well in place; moderate increase of connective tissue about it noted. Found loosely adherent to underlying muscle. Sciatic and transplant with fascial sheath removed and fixed in ammoniated alcohol for pyridine-silver staining. Only fair differential neuraxis staining attained. Tissues not well embedded; sections much torn.

Microscopic findings.—In cross sections of the transplant and the fascial sheath, it is found that the sheath is surrounded by dense layers of fibrous tissue. Sheath in close relation to nerve transplant, very little connective tissue intervening. The transplanted nerve presents areas in which the old neurolemma sheaths are either broken down or distended with detritus and phagocytic cells with lipoid globules. Only a few neuraxes can be traced from the distal end of the central stump, through the transplant, to the distal popliteal. This is no doubt in part accounted for by the imperfect differentiation of neuraxes attained in the pyridine-silver staining.

Experiment No. 247.—Dog No. 4; medium size; full grown; 66 days. June 13, 1918, right sciatic exposed; internal popliteal freed. Left ulnar exposed and freed. A segment of 2.5 cm. length taken from the left ulnar transplanted to the resected right internal popliteal. One central and distal waxed, fine silk thread suture placed; good approximation. A fascial sheath taken from the right fascia lata of the same dog wrapped about the transplant and the resected nerve ends. One central and distal stay suture and three intervening sutures placed. Wound not quite dry, slight oozing, which was not fully controlled. The three wounds closed. August 18, killed. Much emaciated; had not been active for several days; no neurotrophic changes right hind foot. On exposing the right sciatic, the external popliteal is found adherent to the fascial sheath. Fascial sheath found well in place; forms closely fitting tube, surrounded by fibrous tissue; only moderately adherent to underlying muscle. Quite distinct central bulb, evident through the transplant. Sciatic and transplant with fascial sheath removed and fixed in ammoniated alcohol for pyridine-silver staining. Distal posterior tibial fixed in neutral formalin. Good differential neuraxis staining attained. Tissues not well embedded; sections torn.

Microscopic findings.—In cross sections of the nerve transplant and the fascial sheath, it may be observed that the sheath is surrounded by a relatively thick layer of fairly dense fibrous tissue. In alternate cross and longitudinal sections of operated nerve, it may be seen that neuraxes pass from the distal end of the central bulb, through the transplant into the distal popliteal.

Experiment No. 248.—Dog No. 40; medium size; dog not quite full grown; 65 days. July 7, 1918, left sciatic exposed; internal popliteal freed. Right ulnar exposed and freed. A segment of 3.0 cm. length taken from the right ulnar transplanted to the resected left internal popliteal. One central and distal suture of No. 00 catgut placed. Approximation not satisfactory; not as good as when waxed, fine silk thread is used for suture. A fascial sheath taken from the left fascia lata of the same dog wrapped about the transplant and resected nerve ends. Central and distal stay sutures and one intervening suture all of fine silk thread placed. Good fascial tube formed. Dry wound. The three wounds closed. September 10, killed. Dog much emaciated, severe skin disease. On exposing the left sciatic, external popliteal found adherent along side of the fascial sheath. Fascial sheath found well in place; its proximal and distal ends not clearly demarked; moderate increase of connective tissue about it; adherent to underlying muscle. No distinct central bulb made out. Calf muscles exposed; atrophic; do not respond when nerve is cut. Sciatic and the transplant with the fascial sheath removed and fixed in ammoniated alcohol for pyridine-silver staining. Very good differential neuraxes staining attained.

Microscopic findings.—Only indistinct central bulb evidenced structurally. In cross sections of the transplant and sheath, sheath is found surrounded by a relatively loose layer of fibrous tissue. The transplanted nerve clearly demarked, its perineural sheath not materially thickened, between these perineural sheaths and the inner surface of the fascial sheath a layer of loose fibrous tissue. In the transplanted nerve many new neuraxes, singly or in small bundles, observed; endoneural connective tissue only moderately increased. These

new neuraxes can be traced through the transplant and distal wound into the distal popliteal to the level of the calf muscles. Partial regeneration of the distal popliteal attained.

Experiment No. 249.—Dog No. 17; medium size, full grown; 106 days. May 14, 1918, left sciatic exposed. Right ulnar exposed. Two segments, each measuring 1.6 cm. taken from the right ulnar transplanted to the resected right sciatic. One central and distal suture of fine Chinese silk for each segment placed; only fair approximation attained. A fascial sheath taken from the fascia lata of the left side of the same dog wrapped about the transplants and the resected nerve ends. One central and distal stay suture and continuous over and over suture between, placed. The three wounds closed. All wounds healed well. August 28, killed. Dog had not been well for some time; nearly moribund when killed. On exposing the left sciatic, moderate increase of connective tissue about the transplant is found; adherent to underlying muscle. Fascial sheath distinctly evident; its central and distal limits not distinctly made out. Nerve distal to transplant presents the appearance of normal nerve. On exposure, the calf muscles seem still somewhat atrophic and are of pale red color. On slowly cutting the sciatic central to sheath and transplant, no contraction of calf muscles; this may in part be accounted for by condition of dog when killed. Sciatic with the transplant and sheath removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential neuraxis staining attained.

Microscopic findings.—Distinct central bulb evidenced structurally. In cross sections of the transplants and sheath, the fascial sheath appears not to have been reduced in thickness and is found surrounded by a layer of relatively dense fibrous tissue. The two transplanted ulnar segments clearly demarked within the fascial tube. Their perineural sheath relatively thick, but the funicular structure is not lost. Very little connective tissue found between the perineural sheaths and the fascial sheath. Each of the transplant nerve segments, as seen in cross sections, contains numerous new neuraxes; in about equal number in two nerve segments. These neuraxes can, in sections, be traced through the distal wound to the distal sciatic, found approximately equally distributed through its several funiculi. Regeneration of the central end of distal sciatic attained.

Experiment No. 250.—Dog No. 42; large dog; full grown; 268 days. August 21, 1918, right sciatic exposed; internal popliteal freed. Left ulnar exposed and freed. A segment of 3 cm. length taken from the left ulnar transplanted to the right internal popliteal. One central and distal waxed, fine silk thread suture placed. Centrally good approximation; distally a second, an epineural, suture placed; approximation fair. Fascial sheath taken from the fascia lata of the right side of the same dog, wrapped about transplant and the resected nerve ends. Central and distal stay sutures and five intervening half mattress sutures placed. Good tube formed. The three wounds closed. May 16, 1919, killed. Dog in good condition; walks well, but does not climb stairs as easily as normal dog; no neurotrophic changes right hind foot. On exposing the right sciatic external popliteal bundle found free. Quite marked increase of connective tissue about the transplant noted, so that fascial sheath is not clearly made out. Calf muscles exposed; these have the appearance and size and color of normal muscle. Cutting of nerve central to transplant causes good contraction of calf muscles; movement of toes feeble and indistinct. Nerve and transplant with sheath fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—In cross sections of the transplant and sheath, fascial sheath is clearly demarked; does not appear to have been reduced in thickness by absorption; surrounded by a relatively dense layer of fibrous tissue, containing here and there small lobules of adipose tissue. The transplanted ulnar segment presents a funicular structure with perineural sheaths thickened, and endoneural connective tissue materially increased. A loose connective tissue intervenes between perineural sheaths and fascial sheath; in this there may be observed numerous small funiculi of nerve fibers delimited peripherally by the fascial sheath. The funiculi of the transplanted nerve contain numerous new neuraxes scattered or in small bundles. In series of alternate cross and longitudinal sections, new neuraxes can be traced to the distal popliteal in which, in each of the several funiculi, there may be observed numerous both myelinated and nonmyelinated nerve fibers. Very complete regeneration of the distal popliteal through the transplant attained.

Experiment No. 251.—Dog No. 39; medium size; full grown; 276 days. August 14, 1918, right sciatic exposed; internal popliteal freed. Left ulnar exposed and freed. A segment of 3.5 cm. length taken from the left ulnar transplanted to the resected right internal popliteal. One central and distal waxed, fine silk thread suture placed; good approximation. Fascial sheath taken from the right fascia lata of the same dog wrapped about the transplant and the resected nerve ends. The piece of fascia cut a little too narrow at one end so that complete fascial tube could not be made. Central and distal stay sutures and two intervening half mattress sutures placed. Three wounds closed. May 16, 1919, killed. Dog in very good condition; used right hind leg and foot well; no neurotrophic changes. On exposing the right sciatic, the external popliteal found free. Operated internal popliteal in

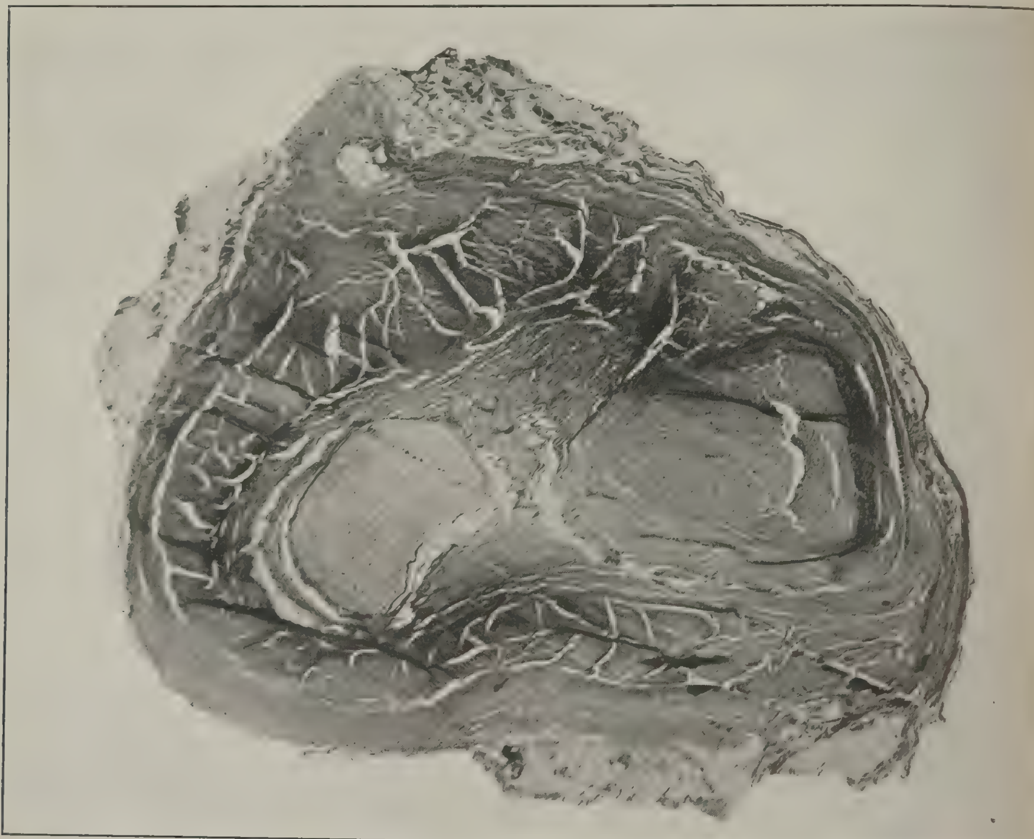

Fig. 237.—Cross section of auto-nerve transplant, wrapped in auto-fascial sheath, Experiment No. 250, terminated 268 days after the operation. Nerve funiculi of transplant are maintained and fully neurotized. Auto-fascial sheath still distinctly evident somewhat over six months after operation

the region of the transplant and sheath surrounded by quite dense connective tissue and adherent to the underlying muscle. Fascial sheath not clearly made out. Calf muscles exposed; these have appearance, both as to size and color, of normal muscle. Sciatic freed from bed and external popliteal resected. On slowly cutting with scissors nerve central to the transplant, good contraction of calf and foot muscles noted. Sciatic, transplant and sheath removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential neuraxis staining attained.

Microscopic findings.—In cross sections of the transplant and sheath, the fascial sheath is found well in place; appears not to have been reduced in thickness by absorption; presents essentially the same structure as in short-time experiments of this series; surrounded by a

distinct layer of fibrous tissue in which many fat cells are seen. The transplanted nerve segment is clearly demarked, having retained its funicular structure. The perineural sheaths of transplant found thickened and for nearly the whole circumference in relation with inner surface of the fascial sheath; very little connective tissue intervening. New neuraxes traced from central stump through the transplant into distal popliteal in which are found numerous myelinated and nonmyelinated nerve fibers arranged singly or in small bundles and separated by endoneural connective tissue which is distinctly increased in amount. Almost complete regeneration of the distal popliteal through the transplant attained.

Experiment No. 252.—Dog No. 42; large dog; full grown; 318 days. July 2, 1918, left sciatic exposed; internal popliteal freed. Right ulnar exposed and freed. A segment of 3.6 cm. length of right ulnar transplanted to the resected left internal popliteal. One central and distal waxed, fine silk thread suture placed; good approximation. Fascial sheath taken from the left fascia lata of the same dog wrapped about transplant and the resected nerve ends. One central and distal stay suture, no intervening sutures placed. Good tube formed. Field not quite dry; oozing controlled by use of adrenalin. The three wounds closed. May 16, 1919, killed. Dog in very good condition, walks well but does not climb stairs as easily as normal dog; no neurotrophic changes left hind foot. Left sciatic exposed; skin adherent along wound line. External popliteal found free. Operated internal popliteal, transplant and sheath surrounded by quite dense layer of connective tissue and adherent to underlying muscle. Fascial sheath not clearly made out. Calf muscles exposed; these have the appearance and size of normal muscle. Cutting of sciatic, after removing external popliteal and removing nerve from bed, central to the transplant, calls forth good contraction of calf and foot muscles. Sciatic, transplant and sheath removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential neuraxis staining attained.

Microscopic findings.—Structural evidence of well-developed central bulb. Downgrowing central neuraxes cross and recross distal part of the bulbous enlargement; evidence of resistance spiral noted. Many neuraxes observed as passing to central end of transplant. In cross sections of the transplant and sheath, fascial sheath is clearly made out for the greater part of the circumference, to one side, it would appear that the lip of the fascial sheath separated, admitting an ingrowth of connective tissue. The transplanted nerve segment clearly demarked, with funicular structure retained. Fairly dense connective tissue intervenes between the several funiculi and the inner surface of the fascial sheath. Numerous myelinated and nonmyelinated neuraxes are transmitted by the transplant to the distal popliteal, cross and longitudinal sections of which present an appearance which resembles that of a nearly completely regenerated nerve.

Experiment No. 253.—Dog. No. 39; medium size; full grown; 326 days. June 24, 1918, left sciatic exposed; internal popliteal freed. Right ulnar exposed and freed. A segment of 3.2 cm. length of the right ulnar transplanted to the left internal popliteal. One central and distal waxed, fine silk thread suture placed; good approximation. Fascial sheath taken from the left fascia lata of the same dog wrapped about transplant and the resected nerve ends. One central and distal and two intervening half mattress sutures placed. Good tube formed. Wound not quite dry; oozing controlled by use of adrenalin. The three wounds closed. May 16, 1919, killed. Dog in very good condition; uses left leg well; no neurotrophic changes. On exposing left sciatic, external popliteal found free. Operated internal popliteal surrounded by relatively dense layer of fibrous tissue, adherent to underlying muscle. Distal nerve has the appearance of normal nerve. Calf muscles exposed; these have the appearence of normal muscle. After freeing sciatic from bed and cutting the external popliteal, slowly cutting with scissors the sciatic central to transplant, calls forth good contraction of calf and foot muscles. Nerve, transplant and sheath removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential neuraxes staining attained.

Microscopic findings.—Central neuraxes pass without special line of demarcation to transplant. In cross sections of transplant and sheath, fascial sheath found well in place and not materially reduced in thickness through absorption; covered on its outer surface by distinct layer of fibrous tissue. The transplanted nerve segment clearly demarked; perineural sheaths thickened, these in close relation to inner surface of the fascial sheath. Numerous small

funiculi of nerve fibers in the connective tissue within the fascial sheath, but outside of perineural sheath, observed; especially to one side. Numerous neuraxes, both myelinated and nonmyelinated, transmitted by the transplant to the distal popliteal, which in cross and longitudinal sections presents the appearance of a nearly completely regenerated nerve.

The experiments of Series No. 17, 14 in number, are sufficiently varied as to time under observation and sufficiently numerous to admit of formulating certain general deductions relative to auto-fascial sheaths. Experiments No. 250 to No. 253 were under observation for periods varying, respectively, from somewhat over 8 months to nearly 11 months, and in each of these experiments it is noted that the fascial sheath could be clearly made out in microscopic sections of the transplant region. These four experiments were studied chiefly with reference to the behavior of the down-growing neuraxes, which were thus fixed for pyridine-silver staining. In preparations stained after this method the fascicular structure of the transplanted fascial sheaths could be clearly made out, the cellular elements were not clearly differentiated. Therefore it can not be stated whether the fixed connective tissue cells—tendon cells—of the fascial sheaths were maintained after transplantation. Lewis and Davis [87] have shown that a fascial tube remains patent for an extended period. In a case in which a fascial tube was used in tendon repair, the sheath was evident 255 days after the operation. In these experiments of long duration there is no distinct evidence of a secondary contraction of the fascial tube. There is found a layer of areolar tissue between the inner surface of the fascial sheath and the perineural sheaths of the funiculi of the transplanted nerve segments. This varies in thickness in the several experiments and also in different regions of the same experiment. The newly formed nerve fibers found within the funiculi of the nerve transplant are of normal appearance and were especially numerous in Experiment No. 253, terminated 326 days after the operation at which the fascial sheath was placed. In this experiment the fascial sheath was well maintained and there was found relatively little loose areolar tissue within the fascial sheath. The contraction noted by Kredel [85] in the case of neurolysis of the tibialis in which the fascial sheath was found contracted 24 days later is not conclusive. It may be asked whether the correct operative procedure was undertaken in the first place. It may be repeated that these experiments seem to indicate that there is relatively little secondary contraction of a fascial sheath. From the experiments here reported it is evident that an auto-fascial sheath of fascia lata does incite connective tissue proliferation even in an aseptic wound in healthy tissue, a wound passing in the main through intermuscular planes. It seems quite impossible to remove a piece of fascia lata without having extravasated blood cells and tissue fragments adhere especially to its outer surface, the more so if a layer of subcutaneous fat is removed with the fascia, as has been recommended. The inner surface is quite smooth if the portion removed is correctly oriented. In all of our experiments a distinct development of fibrous tissue is noted surrounding the fascial sheath. This layer is quite cellular in the experiments of short duration and in it there are found many leucocytes and extravasated red blood cells. In certain of the experiments the fascial sheath was found adherent to the muscle bed, to the extent necessitating dissection; this shows connective tissue pro-

liferation. This newly formed connective tissue surrounding the fascial sheaths, even in aseptic wounds in healthy tissue, on subsequent contraction and cicatrization may be regarded as having deleterious effect on the structural and functional regeneration of an injured nerve, sheathed by fascial sheath, rather than the secondary contraction of the fascial sheath itself. While thus inciting connective tissue growth, the fascial sheath does appear to retard the growth of connective tissue into the central and distal wound and the immediate environs of a nerve transplant. Experiment No. 252 bears on this indirectly. In this experiment, studied 318 days after the primary operation, the fascial tube appears to have opened along the side. There was an ingrowth of connective tissue through this cleft, to the extent that a fairly dense layer of connective tissue intervenes between the nerve funiculi and the inner surface of the fascial sheath, much more so than when the fascial sheath remained closed in tube form as in the majority of the experiments. However, even in this experiment there was found good neurotization of the distal segment through the nerve transplant.

The general conclusion seems warranted that an auto-fascial sheath is very slowly absorbed, evidence of its persistence having been noted nearly a year after it was placed at operation in the wound in healthy tissue. However, even in aseptic wounds in healthy tissue there is noted a distinct proliferation of the surrounding connective tissue, which would prejudice against the use of fascial sheaths in connection with operations of nerve repair, especially where such operations pass through cicatricial tissue. It would appear that auto-fascial sheaths incite more connective tissue proliferation than does alcoholized Cargile membrane, the application of which is technically much simpler and serves every purpose that could be gained on use of a fascial sheath.

SERIES NO. 18

AUTO-NERVE TRANSPLANTS WRAPPED IN FORMALIZED ARTERIAL SHEATHS

This short series of experiments was suggested through records of clinical and experimental observations in which arteries or veins, used either fresh or after fixation and taken as auto-, homo-, or heterogenous vessels were placed as a wrapping or as a tube to ensheath the suture lines in operations for repair of peripheral nerves. To review in extenso the literature involved is not here justifiable. The brief experimental observations of Foramitti,[88] have influenced later operators and experimenters and may thus be given brief consideration here, the more so since we have followed his method of preparing arterial tubes, though Büngner [27] some years earlier had used a segment of a sterilized human brachial artery to bridge a nerve section. We shall consider "tubular sutures" under Series No. 20, in connection with which series the bridging of nerve defects by means of tubular structures will be considered. Ensheathing a nerve suture after severance, or a nerve transplant with a tubular structure is not a "tubular suture" in the correct use of this term. Three animals were operated by Foramitti. Both fresh and hardened arteries were used, either applied to a liberated nerve, by cutting the vessel wall longitudinally and slipping the vessel wall over one end of a resected nerve, making a central nerve flap and moving the arterial

segment so as to cover the field of operation; or, as a tubular suture. The longest observation, that of tubular suture, extended only six weeks. Foramitti found that on use of both fresh and hardened arteries, the inclosed peripheral nerve tissues was only lightly adherent to the wall of the artery. The experiments of Foramitti are not conclusive and leave further doubt when he states "die physiologische Function des Nerven war hergestellt," in speaking of a section and sutured sciatic of the dog studied three weeks after operation. We have used in this series only prepared arterial walls, taken from the carotid of large dogs, and used for the purpose of making a tubular sheath after nerve transplantation. The arteries used were prepared as follows: The carotids of large dogs were stretched over glass tubes of suitable size, were then fixed in 5 per cent to 10 per cent formalin solution for 48 hours, washed in water for 24 hours, boiled in distilled water for 20 minutes, and then stored in 70 per cent to 95 per cent alcohol. They were stored on glass rods in the alcohol in wide mouthed, glass-stoppered bottles, for several days to several weeks depending on the time when they were used at operation. Before use at operation an arterial segment of required length was slipped from the glass rod, cut longitudinally along a line and placed in sterile salt solution for about 30 minutes. The arterial sheath thus prepared was then wrapped about the nerve transplant, sutured in place and allowed to extend 5 mm. to 8 mm. over the central and divided suture lines, and was fixed in place by central and distal stay sutures and intervening half mattress sutures, using for suture fine, waxed silk thread. Experiments with fresh arteries or veins used as sheaths were not made; neither have we tested autogenous nor heterogenous vessels. Foramitti recommended the use of formalized arteries of the calf. With the treatment given the tissue, namely, formalin fixation, boiling for 20 minutes and storage in 95 per cent alcohol, it is to be questioned whether homogenous vessels obtained from amputations or even at autopsy (in selected cases) could not be used for ensheathing operated nerves in human surgery. The experiments of Eden [89] of inserting the central and distal ends of the resected anterior crural through fine slits into the femoral artery or vein, with the circulation maintained, did not seem to us worthy of repetition.

The protocols of experiments on the use of formalized arterial walls for the purpose of ensheathing nerve transplants are as follows:

PROTOCOLS

Experiment No. 254.—Dog No. 50; large dog; full grown; 6 days. July 17, 1918, left sciatic exposed; internal popliteal freed. Right ulnar exposed and freed. A segment of 3 cm. length transplanted to the resected left internal popliteal. One central and distal waxed, fine silk thread suture placed; centrally fair, distally good approximation attained. A segment of formalized artery of a dog, split longitudinally along one side, placed so as to surround the transplant and the resected nerve ends. A central and distal stay suture and three intervening half mattress sutures placed. Adrenalin used to obtain dry field. Wounds closed. July 23, dog found dead in the morning. The superficial wound seemed healed. On reopening wound, evidence of infection noted in deep wound; parts congested. Transplant and tube surrounded by sanguineous exudate. Arterial sheath found well in place. The nerve transplant and the arterial sheath removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—As seen in cross sections of the transplant and sheath, arterial sheath forms a well-closed tube with edges overlapping. About the sheath blood coagulum, tissue detritus, numerous wandering leucocytes and phagocytes. Within the sheath relatively few leucocytes. In longitudinal sections of the region of the central and distal wounds leucocytes have penetrated for a distance into the central and distal stump, and central and distal ends of the transplant, where they are found between the nerve fibers as also within the neurolemma sheaths. The nerve fibers of the transplanted nerve segment present little evidence of beginning degeneration. Their myelin sheaths stain pale, but as yet no distinct evidence of myelin fragmentation. Proliferation of sheath cell nuclei not observed.

Experiment No. 255.—Dog No. 48; medium size; full grown; 57 days. July 15, 1918, left sciatic exposed; internal popliteal freed. Right ulnar exposed and freed. A segment of 2.5 cm. length of right ulnar transplanted to the resected left internal popliteal. One central and distal waxed, fine silk thread suture placed; good approximation. An arterial sheath, formed by cutting longitudinally a segment of formalized carotid artery of a dog and wrapped about transplant and resected nerve ends placed. One central and distal stay suture and two intervening half mattress sutures used. Good tube formed. Dry field after using adrenalin. Wounds closed. September 10, dog found dead in the morning; much emaciated. On exposing the left sciatic, arterial sheath is found well in place. Proximal and distal ends of sheath covered with connective tissue and adherent to epineural sheath of the resected nerve. No material increase of connective tissue about sheath. Nerve, transplant and sheath fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In cross sections of sheath and transplant, arterial sheath clearly recognized in sections; centrally the lips of the arterial sheath have rolled in so that to one side of the transplanted nerve a segment is exposed; distally arterial sheath forms a tube completely inclosing transplant. In section it may be observed that the elastic tissue of the intima and media, and the fibrous tissue of the adventitia are best preserved; the involuntary muscle of the media still recognizable, though many muscle cells appear fragmented. Only a thin layer of fibrous tissue surrounds the arterial sheath. The transplanted nerve segment has retained its funicular structure, with perineural sheaths materially thickened. Dense fibrous tissue intervenes between nerve and arterial sheath, especially centrally, where sheath is incomplete. Many small medullated fibers found within the transplant.

Experiment No. 256.—Dog No. 45; small dog; full grown; 63 days. July 12, 1918, left sciatic exposed; internal popliteal freed. Right ulnar exposed and freed. A segment of the right ulnar of 3 cm. length transplanted to the resected left internal popliteal. One central and distal waxed, fine silk thread suture placed. Centrally fair, distally good approximation attained. An arterial tubular sheath formed by splitting longitudinally a segment of formalized carotid artery of a dog, and wrapping the same about the transplant and the resected nerve ends. Stay sutures and two intervening half mattress sutures placed. Good tube formed. Wounds closed. September 13, dog nearly moribund; killed. Much emaciated; severe skin disease. On exposing left sciatic, arterial sheath is found well in place. The two half mattress sutures appear to have given away, since a slit can be recognized along one side of "tube," for nearly its whole length. No material increase of connective tissue about the sheath. Nerve, transplant, and arterial sheath removed and fixed in ammoniated alcohol for pyridine-silver staining. Only faint silver staining attained; especially in the region of the transplant.

Microscopic findings.—In cross sections, it may be observed that the arterial sheath forms a closely fitting tube surrounding the transplant. A very thin fibrous tissue sheath surrounds the arterial sheath. Arterial wall not so clearly defined in silver-stained preparations as when other fixatives and certain other staining methods are used. However, in the silver preparation it is possible to differentiate the arterial wall and especially its elastic tissue. The perineural sheath of the transplanted nerve segment in close relation to the inner surface of the arterial sheath, very little connective tissue intervening. In series of longitudinal and cross sections, it is possible to trace numerous neuraxes from the central

stump through the transplant and distal wound to the distal popliteal in which a few scattered neuraxes can be traced distally for a distance of about 2 cm.

Experiment No. 257.—Dog No. 49; medium size; full grown; 117 days. July 16, 1918, left sciatic exposed; internal popliteal freed. Right ulnar exposed and freed. A segment of the right ulnar of 3.5 cm. length transplanted to the resected left internal popliteal. One central and distal waxed, fine silk thread suture placed; good approximation. An arterial sheath made by cutting longitudinally along one side, a segment of a formalized carotid artery of a dog and wrapping same about transplant and resected nerve ends. Stay sutures and three half mattress sutures placed. Good tube formed. Dry field obtained after using adrenalin. Wounds closed. November 10, dog found dead in the morning, much emaciated; severe skin disease. On exposing the left sciatic, arterial sheath found well in place; no material increase of connective tissue about sheath. No distinct central bulb noted. Condition of calf muscles not recorded. Nerve, transplant, and sheath removed and fixed in ammoniated alcohol for pyridine-silver staining. Faint but fairly good differential neuraxis staining attained.

Microscopic findings.—In cross sections of the transplant and sheath, it is observed that arterial sheath forms complete tube about transplanted nerve segment and is surrounded by only a thin layer of fibrous tissue. Sheath in close relation with the perineural sheaths of the transplanted nerve segment, the funicular structure of which is retained; the endoneural connective tissue of the funiculi materially increased. In alternate cross and longitudinal sections, numerous new neuraxes may be traced from the central stump through the transplant to the distal popliteal.

Experiment No. 258.—Dog No. 43; small dog; full grown; 130 days. July 11, 1918, left sciatic freed. Right ulnar freed. A segment of the right ulnar of approximately 3 cm. length transplanted to the resected left sciatic. One central and distal waxed, fine silk thread suture placed. Approximation fair; a small amount of blood exudate in central nerve wound. An arterial sheath made by splitting longitudinally a segment of a formalized carotid artery of a dog and wrapping same about the transplant and the resected nerve ends. Stay sutures and several mattress sutures placed. Good tube formed. Wounds closed. November 18, dog seemed fairly well in the morning; found dead 4 p. m.; seemed in good condition; well nourished; no neurotrophic changes on left foot. On exposing the left sciatic, arterial sheath found well in place, moderate increase of connective tissue about it. No distinct central bulb, only slight enlargement noted. Calf muscles exposed; these slightly atrophic, but of good color. Nerve, transplant, and sheath removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—In cross sections of the transplant and sheath, arterial sheath is found to have been well maintained; forming closely fitting tube about the transplant; with scarcely any connective tissue between transplanted nerve segment and inner surface of sheath and only a thin layer of fibrous tissue surrounding it. In cross and longitudinal sections, it is to be observed that new neuraxes in large numbers may be traced from the central stump through the transplant to the distal popliteal in which numerous neuraxes are found in its peripheral distribution, namely, to the posterior tibial several centimeters above the heel and into the small interfascicular nerve branches in the calf muscles. Regeneration of distal popliteal through the transplant attained.

Experiment No. 259.—Dog No. 44; small dog; full grown; 243 days. July 12, 1918, left sciatic exposed; internal popliteal freed. Right ulnar exposed and freed. A segment of the right ulnar of 3 cm. length transplanted to the resected left internal popliteal. One central and distal waxed, fine silk thread suture placed. Central suture gave way; resutured, one through-and-through suture and one epineural suture; central approximation fair, distal good. An arterial sheath made by splitting longitudinally a segment of the formalized carotid artery of a dog and wrapping the same about the transplant and the resected nerve ends. Two stay sutures and three half mattress sutures placed. Good tube formed. Dry field after use of adrenalin. Wounds closed. March 12, 1919, killed. Dog in good condition; no neurotrophic changes left foot; uses left hind foot and leg well. On exposing the left sciatic no macroscopic evidence of arterial sheath found. No material increase of connective tissue about operated internal popliteal; nerve only moderately adherent to under-

lying muscle. Only small central bulb noted. Calf muscles exposed; these present the appearance of normal muscle. After freeing the operated nerve from bed and slowly cutting with scissors central to the transplant good contraction of calf muscles observed, but only feeble and indistinct movement of the toes noted. Nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential neuraxis staining attained.

Microscopic findings.—Scarcely any structural evidence of a central bulb noted. In longitudinal sections of the central and distal wound region and in cross and longitudinal sections of the transplant no distinct structural evidence of the arterial sheath noted. In the silver stained preparations the presence or absence of the sheath is not readily determined. The transplant and regions of the nerve wounds surrounded by a relatively thin layer of fibrous tissue in which no clear determination of the elastic tissue of the arterial sheath could be gained. In cross sections of the transplant it is to be observed that the endoneural connective tissue is very materially increased. The numerous neuraxes, which can be traced from the central stump through the transplant, within the transplant are found arranged in small funiculi, separated by endoneural connective tissue. These neuraxes can be traced to the distal popliteal, in which they are found in large numbers. Very complete regeneration of the distal popliteal through the transplant attained.

This series of experiments is unsatisfactory to the extent that such a large per cent of the experimental animals died from intercurrent disease not related to the experiments, that a function test could not be made in certain of the experiments in which such test would have been desirable. The whole series could be and was used to determine morphology. It was found, confirming Foramitti, that a formalized arterial tube incites relatively little connective tissue proliferation when placed in normal tissue in aseptic wounds. In the experiments of long standing, the arterial tube was found surrounded by only a relatively thin layer of fibrous tissue which was only loosely adherent to adjacent connective tissue. Between the perineural sheath of the funiculi of the transplanted nerve segment and the inner surface of the arterial sheath there was found only a relatively small amount of areolar tissue. The arterial sheath was clearly made out macroscopically in Experiment No. 258 somewhat over four months after it was placed about the operated nerve. It is more particularly the elastic tissue of the vessel wall that resists absorption, forming a compact tubular structure easily recognized in cross sections of the transplant. There is no evidence of a secondary contraction of the vessel wall after it is placed in the tissue. It is recognized, of course, that a tubular structure which persists for a period of approximately 4 months has fulfilled any useful purpose which may be hypothecated to it, when considered in connection with the wound region in a peripheral nerve. In Experiment No. 259, of nearly 8 months' duration, the arterial sheath used at the operation could not be made out macroscopically nor was it recognized in sections, stained after the pyridine-silver method. The neurotization of the distal segment was very satisfactory in all of the experiments in which an auto-nerve transplant was ensheathed in a formalized arterial tube, especially so in experiments observed for a time sufficient to admit of downgrowth of central neuraxes. Attention is particularly called to the protocols of Experiments Nos. 258 and 259 in this regard. Since formalized arterial sheaths are so easily prepared and may be kept on hand in 70 per cent to 95 per cent alcohol, ready for use on need, the method deserves consideration in surgical practice when sheathing of the suture line in nerve suture or of a nerve transplant after bridging a nerve defect is deemed

necessary. However, this type of sheathing presents no advantage over a sheath or tube formed with a double or triple layer of an alcoholized Cargile membrane, which is more easily prepared and applied. A formalized arterial wall used as sheath or tube appears to incite less connective tissue proliferation than does an auto-fascial sheath or tube as judged by the experimental evidence presented.

SERIES NO. 19

AUTO-NERVE TRANSPLANTS WRAPPED IN AUTOGENOUS-FAT FLAP

Relatively frequent reference is made in literature to the use of pedicled or nonpedicled fat sheaths or flaps in connection with operation for the repair of peripheral nerves or of neurolysis. This method of sheathing an operated nerve was for a time especially recommended in case the nerve repair or liberation was undertaken in the presence of scar tissue. The behavior of a fat flap or sheath, either pedicled or nonpedicled, has not been considered experimentally so far as we are able to ascertain. It has been the intention to extend this series of experiments but for various reasons further experiments were not undertaken. In one of the two experiments, the fat membrane was taken in the region of fascia lata through a skin wound made for this purpose; in the other the fat membrane was taken through the wound exposing the sciatic. The fat membrane was thus taken from subcutaneous tissue. There is of necessity free oozing of blood on liberating a fat layer, with consequent adherence of blood coagulum to the tissue removed. The fat membrane, which had an average thickness of 5 mm., was rinsed in sterile salt solution before it was wrapped about the nerve transplant. It was held in place by several stay sutures made with fine, waxed silk thread. The fat sheath thus made was without pedicle and was autogenous tissue, slightly cooled during manipulation and rinsing in the saline solution.

The protocols of the two experiments under this series are as follows:

PROTOCOLS

Experiment No. 260.—Dog No. 54; large dog; not full grown; 4 days. July 22, 1918, left sciatic exposed and the internal popliteal freed. The right ulnar exposed and freed. A segment of the right ulnar of 3.8 cm. length transplanted to the resected left internal popliteal. One central and distal waxed, fine silk thread suture placed; good approximation. A layer of subcutaneous fat removed from the region of the fascia lata of the left leg of the same dog, trimmed to proper size and rinsed in warm, sterile saline solution to remove the adherent blood, was placed under the transplant and the resected nerve ends and folded over so as to form a fat sheath. Two proximal and two distal stay sutures and three intervening sutures placed; fairly even fat sheath formed. Wounds closed. July 26, dog found dead in the morning. Sciatic wound found open in part; field congested: a small amount of pus noted. Fat sheath of yellow-brown color; soft and pliable. Nerve transplant and fat sheath removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In cross sections of the transplant and fat sheath, it may be observed that the nerve transplant is necrotic and as seen in longitudinal sections of the central wound, had torn free from the central stump. The fat sheath is found to have been penetrated from all sides and through its entire thickness by numerous leucocytes and phagocytes. Many of the fat cells appear collapsed and empty of fat globule; others partially so. The interlobular connective tissue of the fat sheath presents evidence of begin-

ning necrosis, evidenced by fragmentation and curling of fiber bundles, especially of elastic tissue.

EXPERIMENT No. 261.—Dog No. 47; medium size; full grown; 240 days. July 15, 1918, left sciatic exposed; internal popliteal freed. Right ulnar exposed and freed. A segment 2.5 cm. length from the right ulnar transplanted to the resected left internal popliteal. One central and distal suture of waxed, fine silk thread placed; good approximation. A layer of subcutaneous fat removed from the region of the wound, trimmed and washed in warmed, sterile saline solution, placed under nerve and transplant and folded over to form a tube; central and distal stay sutures and several intervening sutures placed. Wounds closed. Sciatic wound healed slowly; stitches did not give away, but small droplets of liquid fat appeared to escape from wound; no infection. March 12, 1919, killed. Dog in good condition; no neurotrophic changes left hind foot. On exposing left sciatic dense, fibrous tissue was found in the line of the wound, and dense fibrous tissue surrounded the operated nternal popliteal. No evidence of fat sheath noted; this replaced by dense fibrous tissue. Large central bulb observed. Nerve in region of transplant of smaller diameter than resected nerve; distal popliteal has the appearance of a normal nerve. Calf muscles exposed; these have nearly recovered full size, are of pale yellow color streaked with light yellow lines. On cutting nerve central to the transplant, distinct though not vigorous contraction of calf muscles observed; feeble toe movements noted. Nerve and transplant removed and fixed in ammoniated alcohol for pyridine-silver staining. Very good silver differentiation attained.

Microscopic findings.—Neither in cross nor longitudinal sections is there observed any evidence of the fat sheath. In the region of central and distal wounds and the intervening transplant, distinct increase of dense fibrous tissue about the nerve. In cross sections of the nerve transplant, distinct increase of the endoneural connective tissue observed. New neuraxes traced from the central stump through the transplant are within the transplant found arranged in small bundles, spaced by intervening connective tissue. New neuraxes found in abundance in the distal internal popliteal in all of its funiculi, traced in peripheral distribution in alternate cross and longitudinal sections. Regeneration of distal popliteal through the transplant with great increase of connective tissue in the field of operation attained.

Experiment No. 260 loses in value by reason of the slight infection of the wound region and the early termination of the experiment by reason of the death of the animal. Attention is called to the relatively early disappearance of the fat from certain of the transplanted fat cells, so that many of these cells appear collapsed, shriveled, and shrunken. There was noted marked leucocyte invasion into the fat flap, perhaps in part to be ascribed to the infection present. It was noted in this experiment and in Experiment No. 261 for a few days after the operation that there was taking place a slight oozing of a lipoid fluid from the wound. It was observed in connection with Experiment No. 261 that the wound healed relatively slowly, though infection was not evident. In this experiment the dog was in good condition throughout the time he was under observation, was active, and was kept nearly eight months after the operation. On exposing the sciatic nerve at the termination of the experiment there was found very marked increase of fibrous tissue in the region of the wound and operated sciatic. This fibrous mass was more dense and more extensive than found after any of the other operations in which the nerve transplant was sheathed. The nerve and the nerve transplant, through which neurotization of the distal segment had taken place, were found embedded in the deeper portion of this fibrous tissue, which was adherent superficially to the skin.

A general deduction seems hardly justifiable on the basis of a single experiment. However, the results here presented argue against the use of a completely detached, autogenous-fat sheath or flap, in connection with operated or liberated peripheral nerves, since the fat membrane appears to be replaced by dense fibrous tissue, persisting only a relatively short time as a fat layer. It is to be questioned whether a pedicled fat layer used as a sheath for wrapping an operated nerve would be maintained for a longer time as a fat layer and thus serve the purpose hypothecated to it.

NERVE SUTURE

SERIES NO. 20

TUBULAR SUTURE WITH USE OF FORMALIZED ARTERY

Tubular suture in the repair of peripheral nerves with loss of substance has been given extensive consideration and came into use relatively early in the development of operative technique as regards peripheral nerve repair. The term "tubular suture" as here employed recognizes the union of severed nerve ends by means of a tubular structure, which may be empty or filled at the time of use by inserting and maintaining in place the central and distal stumps of the severed nerve within the lumen of the tubular structure, centrally and distally. As previously stated, wrapping a nerve after neurolysis or after suture, or after nerve transplantation with a membranous structure is, correctly speaking, not a tubular suture but should be regarded as a procedure for ensheathing an operated nerve. Tubular structures were suggested as a means of union of severed nerves and are to-day used, with a view of maintaining a channel along which central neuraxes (monogenetic view) or central and distal neuraxes (polygenetic view) may be enabled to grow, on the theory that such tubular structures along a certain direct path would prevent connective tissue proliferation and organization between the severed and resected nerve ends and at the same time prevent dispersion of the newly formed neuraxes.

Among the various methods tried by Glück[90] for the purpose of bridging nerve defects was that of tubular suture, made by inserting the severed nerve ends into a "Neuber's bone drain." In no instance did regeneration of the distal stump take place. Vanlair[26] instituted a series of experiments on tubular nerve suture also using "bone drains." In a young dog with the sciatic resected 3 cm. and the ends united by means of a bone drain tubular suture, four months after the operation the tissue intervening between the nerve ends was found to contain many nerve fibers. Nerve fibers were also found in the distal stump. Büngner[27] united the resected and separated nerve ends by means of tubular sutures made from sterilized human brachial artery. At the end of about a month and a half nerve fibers were found in the space between the nerve ends. Huber[30] reported eight experiments in which decalcified bone tubes made from the ulna of chicken were used for purpose of tubular suture of the resected ulnar nerves of dogs. Three of these experiments were observed for a period varying, respectively, from about four months to about five months, and in these the neuraxes regarded as of central origin were found in the central

end of the distal stump. A relatively early absorption of the bone tube was noted in the experiments of shorter duration. The tubes were found replaced by a relatively loose connective tissue, thus leaving a path of less densely organized connective tissue between the severed nerve ends. These several lines of investigation give experimental foundation for two types of tubular structure perhaps more frequently used in practical surgery than others, namely, bone tubes and arterial tubes. Numerous other tubular structures have been used for this purpose. More than mention of the majority of these is not justified here; nearly all have been or should be discarded, since their use is not justified experimentally. Mention is here made of tubes formed of iodoform gauze, Wölfer; [91] of magnesium tubes, Payr; [92] hardened gelatin tubes, Lotheisen; [93] galalith tubes (casein treated with formalin), Auerbach; [94] rubber tubes and rubber tubes filled with serum, Steinthal; [95] rubber bandages, Meuriot and Platon. [81] These and other tubular structures of like nature are more of academic than practical interest and their consideration need not occupy space here. Brief recognition should be given, if only to condemn it, to the method of tubular suture suggested by Edinger,[96] who, largely on theoretic grounds and without sufficient experimental warrant, recommended the use of arteries filled with agar, for the purpose of bridging nerve defects. Edinger appears to have reasoned that if neuraxes would grow into agar or blood serum in tissue culture, a tubular suture filled with agar should prove more serviceable than an empty tube. These "Edinger tubes" were prepared commercially and for a period were used extensively in the German service, even in cases in which a direct suture could have been made. A series of contributions appeared so soon as the observations on the results obtained on the use of the Edinger tube could be ascertained; Stracker [97] and a number appearing in 1917 may be listed here, Hohmann and Spielmeyer, [98] Enderlen and Lobenhoffer, [99] Spitzy, [100] Wollenberg, [101] Blenke, [102] and Eden ,[103] all of whom discredited use of the Edinger tube even in case the prepared artery was filled with autoserum as was later suggested. This method was not tested experimentally in our laboratory but was condemned on a priori considerations. The experimental work reported on briefly by Hohmann and Spielmeyer,[98] in which arterial tubes filled with agar were tested, led to the conclusion that agar in the arterial tubes appeared to block the downgrowth of neuraxes rather than facilitate their growth. The use of fascial tubes in the repair of peripheral nerves with loss of substance was tested experimentally by Kirk and Lewis. [86] They conclude that a defect in a nerve may be successfully bridged by means of a fascial tube, regeneration taking place entirely through nerve fibers growing from the central stump. They give directions and precautions for use of a fascial tube in the repair of peripheral nerves. Their experiments were controlled by study of histologic sections stained after differential neuraxes staining methods and had been completed so recently that they could be considered a part of these experimental observations.

Tubular nerve suture with the use of vessels is mentioned so frequently in literature on the repair of peripheral nerves and to our knowledge had not been given more than passing consideration experimentally since the few experiments made by Foramitti [88] were recorded, that it seemed to us desirable to make

use for this purpose of certain of the ulnar nerves resected to obtain auto-nerve transplants for Series No. 16, No. 17 and No. 18 as previously reported. In all 13 experiments of tubular suture were made. The arteries used were the carotids of dogs. The arteries were obtained from large dogs after bleeding while under anesthesia, were slipped over glass rods of suitable size and fixed in 5 per cent to 10 per cent solution of formalin, for 48 hours; were then washed in water for 24 hours; boiled in distilled water for 20 minutes and placed in 70 per cent to 95 per cent alcohol until needed. Before use, pieces of desired length of the artery selected, were slipped from the glass rod and placed in sterile saline solution for about 30 minutes. On applying the formalized arterial tube for purpose of tubular suture the following procedure became routine: A fine, waxed silk suture armed with a fine needle at each end was passed through the central and distal stumps of the resected ulnar from 2 mm. to 3 mm. from the cut ends. The needles of each suture were then passed through the opposing sides of the formalized arterial tube from 7 mm. to 8 mm. from the respective ends of the tube and the ends of the resected nerve, central and distal, drawn into the lumen of the arterial tube and held in place by knotting the silk sutures over one side of the arterial tube. The wound was then closed by using the necessary fascial and skin sutures. In this series of experiments no nerve transplant was inserted between the resected nerve ends; the ends of the resected ulnar, from 3 cm. to nearly 5 cm. apart in the several experiments, were merely inserted into the ends of the arterial tubes and kept in place by means of stay sutures.

The protocols for the experiments under Series No. 20, tubular sutures with formalized arterial tubes, are as follows:

PROTOCOLS

Experiment No. 262.—Dog No. 50; large; full grown; 6 days. July 17, 1918, right ulnar exposed; resected 3.5 cm. The resected ends of the ulnar inserted into the ends of a segment of a formalized carotid artery of a dog, 4.5 cm. length, and held in place by central and distal stay sutures. Dry field obtained after use of adrenalin; fascia stitched over nerve and arterial tube; wound closed. July 23, dog found dead in the morning. Ulnar wound wide open; arterial tube exposed. Distal end of ulnar pulled out from arterial tube. Ulnar and arterial tube removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—Distal end of central ulnar stump found within the lumen of the arterial tube. In longitudinal sections of this region, the usual degeneration of central stump in region of wound observed. Arterial tube found collapsed to flat ribbonlike structure. Within its lumen, as seen in cross section, is found a small amount of stainable granular precipitate and fine shreds of fibrin; scarcely any cellular elements. Walls of arterial tube well preserved. The looser, outer connective tissue coat of arterial tube invaded by wandering leucocytes, extravasated red blood cells and phagocytes present in large numbers in the tissue surrounding the arterial tube.

Experiment No. 263.—Dog No. 46; small dog; full grown; 17 days. July 13, 1918, right ulnar exposed and resected 3.5 cm. The resected ends of the ulnar inserted into the ends of a segment of formalized carotid artery of a dog, 4.5 cm. length, and held in place by central and distal stay sutures. Adrenalin used to obtain dry field. Fascia stitched over arterial tube; wound closed. July 31, dog found dead in the morning. Superficial wound healed; a dead place found under skin in operative field; fascia healed over arterial tube. Arterial tube found well in place; distinct bulbous enlargement on central ulnar stump. Arterial tube collapsed; appears as flat band. Arterial tube with ulnar nerve re-

moved and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In longitudinal sections, including the distal end of the central stump and the central end of the arterial tube, bulbous end of the central stump found well within arterial tube. Bulbous end of central stump presents early stages of regeneration down-growing neuraxes and rich capillary net. Beyond the end of the nerve, within the arterial tube, felt-work of newly formed fibrous tissue, syncytial protoplasmic bands and capillaries. In cross sections of the arterial tube, about its middle, vessel wall clearly made out; media and greater part of the adventitia intact. Within the lumen of the collapsed tube, newly formed fibrous tissue fibroblasts and here and there capillary sprouts noted; relatively few leucocytes and a stained granular precipitate. Only a thin layer of loose connective tissue surrounds the tube. Distal nerve is found in process of degeneration.

Experiment No. 264.—Dog No. 51; medium size; full grown; 18 days. July 18, 1918; right ulnar exposed; resected 4 cm. Resected ends of ulnar inserted into the ends of a segment of formalized carotid artery of dog, of 4 cm. length. One central and distal stay suture placed. The diameter of the lumen of the tube greater than that of the nerve. Each end of tube split longitudinally for a distance of 0.5 cm., edges overlapped and held in place by half mattress sutures; ends of tube made to fit nerve closely. Wounds closed. August 5, killed. Dog not in good condition. Ulnar wound well healed. On exposing right ulnar, arterial tube is found well in place, united to the resected nerve ends. Arterial tube surrounded by newly formed connective tissue; tube collapsed. Light pressure on it causes a small amount of sanguineous fluid to escape at the distal end. Ulnar and arterial tube removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good differential neuraxis staining attained. Only central bulb and central end of arterial tube cut; tissue did not embed well, sections torn.

Microscopic findings.—In longitudinal sections of the central bulb and the central end of the arterial tube, the normal ulnar can be traced into the bulbous end, clearly evidenced structurally, this bulbous end surrounded by the arterial tube, which is well preserved. Beyond the distal end of this central bulbous enlargement, small bundles of neuraxes can be traced into newly formed connective tissue continuous with the same, this mainly along the inner wall of the arterial tube, for a distance of about 1 cm.

Experiment No. 265.—Dog No. 53; small dog; full grown; 41 days. July 20, 1918, right ulnar exposed and resected 4 cm. As tubular suture, used a segment of a formalized carotid artery of a dog, 4 cm. long. One central and distal stay suture placed. Distally a second suture used to narrow the lumen of the tube. Dry field obtained by use of adrenalin. Wound closed. Five to eight days after operation, slight evidence of infection; stitch abscess. Wound treated with tincture of iodine; apparent infection stopped. August 30, dog found dead in the morning; some emaciation; wound well healed. On exposing the right ulnar, arterial tube found well in place; united to resected nerve ends. Distinct central bulb seen through tube wall. A small amount of sanguineous fluid noted within the tube. Tube surrounded by newly formed connective tissue; adherent to surrounding tissue. Ulnar and arterial tube removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In longitudinal sections of area of junction of the central and distal resected nerve ends and arterial tube, it is to be observed that the arterial wall is united to the resected nerve ends by fibrous tissue. The structure of the arterial wall well preserved as concerns elastic and fibrous tissue, with a layer of fairly dense fibrous tissue on its outer surface. In longitudinal sections of the central end of arterial tube, distinct central bulb is evidenced structurally, beyond which very few structures are traced distally within the lumen of the tube. Cross sections of the arterial tube approximately 1.5 cm. from its central bed, shows the tube collapsed and practically empty; scarcely any cellular elements found within the lumen of the tube in this region and distal thereto.

Experiment No. 266.—Dog No. 57; small dog; full grown; 46 days. July 25, 1918, right ulnar exposed; resected 3.6 cm. A tubular suture made with a 4 cm. long segment of a formalized carotid artery of a dog, held in place by means of one central and distal stay suture. Dry field obtained after use of adrenalin. Wound closed. About 10 days after the opera-

tion, after the wound had healed, the skin of this dog became infected; dog not in good condition. September 8, dog found dead in the morning; emaciated. No neurotropic changes right fore foot. Superficial wound well healed. On exposing nerve, a small pus pocket found over arterial tube; this found to contain a short segment of thread. Arterial tube collapsed; centrally attached to nerve; distally nerve seems to have pulled out of tube. Ulnar and arterial tube removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In longitudinal sections of centrai and distal ends of the arterial tube and resected nerve ends, ends of nerve are found to be within the lumen of the arterial tube and united thereto by means of fibrous tissue. Large central bulb evidenced structurally; this ends free within the lumen of the tube. Surrounding end of bulb, numerous leucocytes and phagocytes; very little structural evidence of organized tissue. In cross sections of the arterial tube, approximately its middle wall, of artery presents evidence of disintegration; elastic layers of media present very wavy course and are widely spaced. Within the lumen of the tube, numerous leucocytes and phagocytes; no organized tissue. It is concluded that there was present slight infection in this experiment.

Experiment No. 267.—Dog No. 55; large; full grown; 47 days. July 22, 1918, right ulnar exposed; resected 3.5 cm. A tubular suture made, using a segment of 4 cm. length of a formalized carotid artery of a dog. One central and distal stay suture placed. Arterial tube cut a little too short so that resected ulnar, after suture, was slightly under tension. Dry field obtained after use of adrenalin. Wound closed. September 8, dog found dead in the morning; much emaciated; severe skin disease. Ulnar wound well healed. On exposing the ulnar, a small dead space is found over the arterial tube with a small amount of sanguineous pus. Arterial tube well in place, united to resected nerve ends. Nerve and arterial tube removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In longitudinal sections of the central and distal ends of arterial tube and the resected nerve ends, the arterial tube is found to be well in place united to resected nerve ends by fibrous tissue. Tube wall very well preserved and found of compact structure. Distinct central bulb evidenced structurally, from the distal end of which there is found to extend into the lumen of the tube a newly formed connective tissue consisting of fine interlacing fibers and fibroblasts practically filling the collapsed lumen of the tube and extending within the lumen to the distal nerve segment; arterioles, venules, and capillaries found in this tissue. Within this tissue, traced in successive series from the central bulb, are also found small funiculi of nerve bundles, especially along the inner surface of the arterial tube. These nerve bundles do not extend to the distal nerve, which is degenerated. Sections present no evidence of infection within the lumen of the arterial tube.

Experiment No. 268.—Dog No. 48; medium size; full grown; 57 days. July 15, 1918, right ulnar exposed and resected approximately 3 cm. A tubular suture made by using a 4 cm. segment of the formalized carotid artery of a dog. One central and distal stay suture placed. Wound closed. September 10, dog found dead in the morning; much emaciated, ulnar wound well healed. On exposing the right ulnar, increase of connective tissue in region of wound noted; possible evidence of deep wound infection not recognized. Arterial tube found well in place, ends adherent to resected nerve ends. Large central bulb within the arterial tube noted. Tube collapsed; surrounded by connective tissue, adherent to surrounding tissues. Ulnar nerve and arterial tube removed and fixed in neutral formalin. Sections stained in iron-hematoxylin and picro-fuchsin; safranine and licht grün.

Microscopic findings.—In central and distal longitudinal sections, arterial tube is found firmly united to resected nerve ends. The large central bulb is found to be partly within and partly without the lumen of the arterial tube; from the distal end of the bulb there extends into the lumen of the tube a vascularized fine fibrillar connective tissue which extends to the distal ulnar. In this tissue small funiculi of nerve fibers may be observed in cross sections of the tube about its middle region. The distal ulnar stump completely degenerated.

Experiment No. 269.—Dog No. 45; medium size; full grown; 63 days. July 12, 1918, right ulnar exposed; resected 3.5 cm. A tubular suture made by using a segment of 4.5 cm. length of a formalized carotid artery of a dog. One central and distal stay suture placed.

Arterial tube was cut a little too long; when sutured in place was found bent a little in its middle portion. Wound closed. September 13, killed. Dog in poor condition; emaciated; skin disease. Superficial wound well healed. On exposing nerve, slight evidence of deep wound infection noted. Arterial tube found pulled free from central ulnar stump; distally united to distal ulnar segment. The central stump found to end in large central bulb, from the free end of which no nerve fibers can be traced distalward. Only central bulb removed and fixed in ammoniated alcohol for pyridine-silver staining. Pale but differential silver staining attained.

Microscopic findings.—In longitudinal sections of the central bulb, distinct structural evidence of the central end of the arterial tube found in the peripheral connective tissue sheath of the bulb; arterial tube appears to have been torn rather than to have pulled free from the central stump. A few neuraxes can be traced beyond the distal end of the bulb extending for a short distance into the surrounding connective tissue.

Experiment No. 270.—Dog No. 49; small dog; full grown; 117 days. July 16, 1918, right ulnar exposed; resected 4 cm. A tubular suture made by using a segment of 4.5 cm. length of formalized carotid artery of a dog; one central and distal stay suture. Quite a little venous bleeding finally controlled by use of adrenalin; dry field; wound closed. November 10, dog found dead in the morning; emaciated; no neurotrophic changes right fore foot. On exposing the right ulnar, arterial tube is found well in place, firmly united to resected nerve ends. Only moderate amount of connective tissue surrounds nerve ends and arterial tube; only loosely adherent to the surrounding tissue; tube collapsed. Distinct bulbous enlargement of the distal end of the central ulnar stump. A segment of the central ulnar. arterial tube and 10 cm. of distal ulnar removed, fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained; tissue not well embedded; difficult to cut after silver impregnation.

Microscopic findings.—In a series of longitudinal sections including the central bulb and central end of the arterial tube, distinct central bulb evidenced structurally, from the distal end of which many neuraxes, grouped in small funiculi, separated by connective tissue pass distally in the lumen of the arterial tube. As seen in cross sections at successive levels, neuraxes more abundant in the central than in the distal part of the arterial tube, though numerous neuraxes reach the distal end of the arterial tube and pass into the central end of the distal ulnar, in which they may be traced at least 5 cm. distal. In the distal ulnar the neuraxes are fairly evenly distributed through the several funiculi. Partial regeneration of the distal ulnar through arterial tubular suture.

Experiment No. 271.—Dog No. 43; small dog; full grown; 130 days. July 11, 1918, right ulnar exposed and resected 3 cm. A tubular suture made by using a segment of 4 cm. length of the formalized carotid artery of a dog; one central and distal stay suture placed; distally an additional half mattress suture used, to narrow the lumen of the tube. Dry field obtained by using adrenalin. Wound closed. November 18, dog seemed fairly well in the morning; found dead in the afternoon. Seemed in good condition; no neurotrophic changes right fore foot. On exposing the right ulnar, arterial tube is found well in place; it seems of smaller diameter than when used; firmly united to resected nerve ends; only partly collapsed. Only moderate amount of connective tissue found about the tube; loosely adherent. Large central bulb noted; central end of distal ulnar only slightly enlarged. Distal ulnar of small diameter, but has not the appearance of a degenerated nerve. Fore leg muscles supplied by ulnar exposed; they are found only slightly atrophic and of pale red color. Ulnar nerve and arterial tube removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good silver differentiation attained.

Microscopic findings.—In series of cross and longitudinal sections, the wall of the arterial tube found well preserved. Wall of tube found contracted and presenting a number of folds. In cross section it is observed that the lumen of the tube contains fairly dense fibrous tissue which in the sections is retracted slightly from the inner wall of the tube. Within this connective tissue core, and occupying the central field proximally, more to one side distally, are found numerous small funiculi of nerve fibers. These may be traced, becoming less numerous distally, to and into the distal ulnar in which a relatively small number of neuraxes, about equally distributed through the several funiculi, may be traced distally for several

centimeters; to the limit of the sections. Partial regeneration of distal ulnar through arterial tube attained.

Experiment No. 272.—Dog No. 47; medium size; full grown; 240 days. July 15, 1918, right ulnar exposed; resected a little over 3 cm. A tubular suture made by using a segment of about 4 cm. length of a formalized carotid artery of a dog; one central and distal stay suture placed. Dry field. Wound closed. March 12, 1919, killed. Dog in good condition; no neurotrophic changes. Ulnar nerve exposed, first as it passes over elbow. Pressing and touching nerve in this region with forceps, calls forth good contraction of forearm muscles supplied by ulnar. After exposing forearm muscles, cutting the nerve below the elbow causes good contraction; individual muscles seen to contract. The ulnar was then exposed centralward. Arterial tube found well in place and firmly united to resected ends of ulnar. Quite large central bulb encased in central end of arterial tube; central end of distal ulnar not materially enlarged. Ulnar with arterial tube removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—In cross sections of the arterial tube, this is found collapsed to nearly form of ribbon; vessel wall found well preserved; not materially reduced in size by absorption. In a series of longitudinal sections including the central bulb and central end of the arterial tube, it may be observed that from the distal end of the bulb there extend downward numerous small, intercrossing funiculi of nerve fibers, certain of which are myelinated. Within the lumen of the tube, best seen in cross sections, only small amount of fibrous tissue separated these larger and smaller nerve funiculi, which can be traced in decreasing number to the distal ulnar in which they extend distalward in relatively large number. Fairly complete regeneration of distal ulnar, through formalized arterial tube attained.

Experiment No. 273.—Dog No. 44; small dog; full grown; 243 days. July 12, 1918, right ulnar exposed; resected 3.5 cm. A tubular suture made by using a segment of 4 cm. length of a formalized carotid artery of a dog; one central and distal stay suture placed. Dry field after use of adrenalin. Wound closed. March 12, 1919, killed. Dog in very good condition. No neurotrophic changes. Right ulnar first exposed near elbow, after freeing from connective tissue and then slowly cutting with scissors, feeble contraction of forearm muscles observed. On exposing the ulnar centralward, it was observed that the arterial tube was attached to the central ulnar stump. The arterial tube could be easily traced for distance of a little more than 2 cm., but appeared to have pulled free from the distal ulnar stump. Several fine nerve bundles could be traced in the connective tissue beyond the distal end of the arterial tube, but could not be followed to the distal stump; some intervening connective tissue having unfortunately been removed before the condition was recognized. It would seem that even though the distal tubular suture had given way, certain of the down-growing neuraxes led to the neighborhood of the distal ulnar stump, had reached and penetrated it, with a result of partial regeneration of the nerve. As the experiment, beyond the function test, owing to accident, was incomplete, tissue was not removed for microscopic study.

Experiment No. 274.—Dog No. 52; medium size; full grown; 300 days. July 19, 1918, right ulnar exposed and resected 4 cm. A tubular suture made, using a segment of 4.5 cm. length of a formalized carotid artery of a dog; one central and distal stay suture placed. Dry field; wound closed. May 15, 1919, killed. Dog in good condition. No neurotrophic changes; appears to use right fore leg as well as left. On exposing the ulnar, it is found that the arterial tube remained connected with the distal ulnar stump, was much collapsed and folded to one side, the central end of the arterial tube having pulled free from the central ulnar stump; presumably soon after the operation. Large bulbous enlargment on the distal end of the central ulnar, surrounded by quite dense fibrous tissue. No nerve bundles could be traced beyond the bulb. The distal ulnar segment completely degenerated, and gives no response on cutting or crushing at the level of the elbow. Central ulnar bulb removed for study of neuroma. Experiment not successful as far as showing tubular suture is concerned. The fact that a formalized artery may remain embedded in normal tissue for more than seven months, is of interest.

In this series, in which the use of formalized, arterial, tubular nerve sutures is considered, it is observed that the formalized arteries placed in aseptic wounds in normal tissue at the time of operation remain unabsorbed for a relatively long time, for a period of approximately 8 months, thus fulfilling very well certain of the requirements of a tubular nerve suture, namely, that of remaining unabsorbed until the time when central neuraxes may have opportunity to reach the distal stump. Experiment No. 272 is the most satisfactory of those of this series observed for a long time after operation, in this case 240 days. A distance of 3 cm. was successfully bridged by means of tubular suture as attested by function tests and by histologic examination. The arterial tube was found well in place, though much collapsed, with lumen nearly obliterated. Within the lumen there was found a small amount of connective tissue and in this numerous small funiculi of nerve fibers, which in the main present a longitudinal course. In Experiments No. 270 and No. 271, of approximately 4 months' duration, neuraxes of central origin can be traced through the lumen of the arterial tube to the distal segment in which they may be followed for a short distance. In a number of the experiments of shorter duration, the observations were terminated by death of the animals from disease not related to the experiment. These observations are listed serially as to time, and the tissues obtained were studied so far as circumstances permitted. It will be noted that distinct neuromata found on the distal end of the central stump and within the lumen of the arterial tubes are described for nearly all of the experiments. There is found within the lumen of the tubes a scanty development of connective tissues which appears to have arisen from fibroblasts derived from the central and distal nerve stumps, rather than from the tissue surrounding the arterial tubes. Whether sheath cells participate in the formation of the syncytial net found within the tube in early stages has not been determined. This fibrous tissue forms a scaffolding on which the neuraxes proceed distalward. It is of special interest to note, and it confirms in a very satisfactory manner the monophyletic view of the regeneration of the distal stump, that the neuraxes within the lumen of the vessel appear first near the central bulb, later progressively more distant the longer the time intervening between the operation and the time of observation. The distal segment remains degenerated until the central neuraxes have reached in their downgrowth the distal portion of the arterial tube and thus the central end of the distal stump.

These experiments may serve to show that tubular suture may, under favorable conditions, serve to convey neuraxes from the central to the distal stump of a severed and resected nerve. This has been shown for tubular suture made with decalcified bone tubes, Huber,[30] for fascial tubes by Kirk and Lewis,[86] and for formalized arterial tubes in the experiments here recorded. However, the method of tubular suture can not be recommended for adoption in surgical practice since other methods for bridging nerve defects offer greater assurance for success. "Tubulization offers a single large path for the downgrowth of neuraxes and, for this reason, is mechanically inferior to nerve transplantation for nerve regeneration, since the latter method offers numerous small paths which serve as individual conducting tubules for the neuraxes" (Stookey).[9]

SERIES NO. 21

TENSION SUTURES; RESECTED NERVES SUTURED UNDER EXTREME TENSION, WITH OR WITHOUT SECONDARY WRAPPING IN ALCOHOLIZED CARGILE MEMBRANE OR FORMALIZED ARTERIAL SHEATHS

In this series of 13 experiments the ulnar nerve of dogs, which had been resected for the purpose of obtaining auto-nerve transplants to be used in Series No. 16, No. 17, and No. 18, was used for the purpose of testing nerve suture under tension, the ends of the resected nerve being brought together as closely as possible by direct suture. It is clearly recognized in surgical practice that a distance of separation of severed and resected nerve ends to the extent of 2 cm. to 3 or 4 cm. of one of the major extremity nerves can be overcome, as a rule, by liberation of the nerve and the application of traction, so that a suture may be placed. The extent of approximation which can be attained in this way varies with the nerve and, to some extent, with the location of the injury. We have reached the conclusion, based on experimental observations, that nerves can be freely mobilized without material injury or causing degeneration. In many of our experiments on the sciatic of dogs, after exposing the nerve for its entire length from the sciatic notch to the popliteal space, and then liberating the nerve from its bed and separating the two popliteal branches for their entire length, the internal popliteal branch alone was operated upon, resected, and otherwise treated while the other branch remained intact. In such procedure, the external popliteal branch, though freely manipulated and perhaps under tension, showed no sign of degeneration and functioned without interruption. We feel warranted in saying that quite extensive liberation of a human nerve is permissible if necessity demands and that this is without material injury to the nerve nor does it lessen the progress of regeneration. In every nerve injury with severance of continuity and loss of nerve substance an attempt should be made to approximate the severed nerve ends and perform a simple suture. The extent of tension permitted in connection with a nerve suture is a question of judgment, and experience will enable decision for each case; no general rule can be given not applicable to general surgical procedure. Owing to the unsatisfactory reports found in the literature relative to various methods of procedure for bridging nerve defects surgeons have shown a timidity and hesitancy with regard to adopting methods of nerve transplantation and have attempted by direct suture to maintain in apposition nerve ends after loss of substance when, to accomplish such, the united nerve ends and sutures were under tension to a degree not justified. Such a condition we have endeavored to simulate in this series of experiments. A resection in the ulnar of a dog above the elbow to the extent of from 2.5 cm. to nearly 5 cm. is a relatively much greater loss of nerve substance than a segment of equal length removed from the human ulnar. In our experiments, after the resection of the ulnar nerve for purpose of obtaining an auto-nerve transplant which was used to bridge a defect in the sciatic of the same dog, followed by wrapping the region of the transplant after one of the methods described under Series No. 16, No. 17, and No. 18, the operation on the sciatic nerve was completed to closure of the skin wound; in the meantime protection was given to the ulnar wound.

The details of the operation on ulnar nerve varied somewhat in the several experiments in this series. In the majority of the operations a silk suture was passed through the central and distal stumps of the resected nerve and then, after liberating the nerve centrally and distally, however, without freeing the distal ulnar from its fibrous bed at the elbow, tension was applied mainly by means of the suture and the nerve ends approximated as nearly as could be without breaking the suture or tearing it out. In some of the experiments it was possible to bring the nerve ends in relatively close approximation, in others a distance of 1 cm. or even more intervened between the nerve ends. In many of the experiments the field of suture was wrapped with several layers of alcoholized Cargile membrane with about 1 cm. of the adjacent nerve ends included. This was closely wrapped about the nerve to form a close-fitting tube. In certain of the experiments an arterial tube segment, made from a formalized carotid artery of a dog, was slipped over the central nerve stump prior to suture of the nerve ends, and after the suture was completed was placed over the region of the tension suture and the adjacent nerve ends. In other experiments no protection was given to the suture region. Purposely no attempt was made to immobilize the operated foreleg in these experiments. The tension used in bringing together the resected nerve ends in these experiments, it is thought, was no greater than that used by certain operators in the repair of injured nerves with loss of substance in humans; and in this respect our experiments are comparable to their operations.

PROTOCOLS

Experiment No. 275.—Dog No. 40; medium size; not full grown; 22 days. August 19, 1918, left ulnar exposed; resected nearly 4 cm.; resected ends retracted so that they were 4.6 cm. apart. One waxed, silk thread suture was passed through each end of the resected ulnar and then brought together as closely as possible; the sutures tied. The suture line was wrapped with two layers of alcoholized Cargile membrane, forming a tube about 2 cm. long. Fascia stitched over nerve; wound closed. The left forearm was not immobilized. September 10, dog killed; much emaciated. Ulnar wound healed. On removing skin and fascia over the ulnar field, it was found that the tension suture had given way; the resected nerve ends were found to be about 3 cm. apart. The central stump terminated in a well-developed bulbous enlargement. The alcoholized Cargile membrane was found partly spread out, embedded in connective tissue. The central bulbous end removed and fixed in ammoniated alcohol for pyridine-silver staining.

Microscopic findings.—Longitudinal sections show typical structure of amputation neuroma.

Experiment No. 276.—Dog No. 30; large; full grown; 44 days. August 15, 1918; left ulnar exposed; resected 3 cm. One through-and-through silk suture passed and resected nerve ends brought together and suture tied. As knot was being tied, nerve ends slipped apart to the extent of 5 mm. The suture line wrapped with double layer of alcoholized Cargile membrane. Fascia stitched over nerve; wound closed. September 28, dog found dead in the morning. Ulnar wound well healed. After removing skin and fascia over ulnar field, it was observed that the suture had given way; resected ulnar ends nearly 3 cm. apart. Large bulbous enlargement found on central ulnar stump. Cargile membrane found adherent to distal stump; folded over and embedded in fibrous tissue. Portions of central and distal ulnar stump removed and fixed in neutral formalin.

Microscopic findings.—Well stained neuroma showing typical neuroma structure; small funiculi of nerve fibers found in connective tissue distal to neuroma.

Experiment No. 277.—Dog No. 3; medium size; full grown; 56 days. June 11, 1918, left ulnar exposed and resected approximately 2.5 cm. One through-and-through silk suture passed and resected nerve ends brought together and tied; resected nerve ends 2 mm. apart Two layers of Cargile membrane wrapped about suture line and about 1 cm. of resected nerve ends. Fascia stitched over nerve and wound closed. Left foreleg not immobilized. August 6, killed. Dog in good condition. On exposing the ulnar, it is found that the resected nerve ends are still in close approximation; about as at the close of operation. No trace of Cargile membrane found. Firm connective tissue surrounds and unites the resected nerve ends. Distinct large central bulb noted. Large segments of central and distal nerve ends with intervening connective tissue removed and fixed in ammoniated alcohol for pyridine-silver staining. Unsuccessful differentiation attained; tissues not well embedded; sections torn.

Microscopic findings.—No trace of Cargile membrane in sections. In longitudinal sections through the wound region, a few new neuraxes distinguished in the central end of the distal ulnar stump. In cross sections of distal ulnar 2 cm. distal to wound, nerve presents the appearance of a degenerated nerve.

Experiment No. 278.—Dog. No. 41; small dog; full grown; 61 days. June 28, 1918, right ulnar resected 4 cm. One through-and-through waxed, silk suture passed, and under tension resected nerve ends brought together and suture tied. After suture was tied the resected nerve ends were found to be 1 cm. apart. Fascia stitched over the nerve and wound closed. August 28, dog found dead in the morning. Wound well healed. On exposing the right ulnar, it was observed that the suture had given way; the resected nerve ends were found to be about 3 cm. apart. Large bulbous end on central ulnar stump observed; no nerve bundles can be traced beyond it distally. The central ulnar bulb was removed and fixed in ammoniated alcohol for pyridine-silver staining.

Microscopic findings.—Typical neuroma evidenced structurally.

Experiment No. 279.—Dog No. 38; medium size; full grown; 61 days. June 21, 1918, right ulnar exposed; resected approximately 3 cm. One through and through silk thread suture passed and resected nerve ends brought together under tension. After tying knot, approximation of nerve ends good. Fascia stitched over nerve and wound closed. Foreleg not immobilized. August 22, dog reoperated in the morning; found dead early afternoon; seemed in very good condition. On exposing the right ulnar, it is evident the suture had given away; resected nerve ends found nearly 3 cm. apart. Very large bulbous enlargement noted on end of central ulnar stump. No nerve fibers can be traced from the distal end of this bulb. Central ulnar and bulb removed and fixed in ammoniated alcohol for pyridine-silver staining.

Microscopic findings.—Very large neuroma, with typical neuroma structure evidenced structurally.

Experiment No. 280.—Dog No. 40; medium sized dog; full grown; 47 days. July 25, 1918, right ulnar exposed and resected 4 cm. One through-and-through suture of No. 00 catgut passed and tension made; catgut suture broke. A double silk thread suture passed and under tension the resected nerve ends brought together; suture tied. Fascia stitched over the nerve; wound closed. Right foreleg not immobilized. September 10, killed. Dog much emaciated; skin disease. On exposing the right ulnar, it is evident that the suture had given away; resected nerve ends about 3 cm. apart. Large central ulnar bulb; within it, suture is recognized. Central ulnar and central end of distal ulnar stump removed and fixed in ammoniated alcohol for pyridine-silver staining.

Microscopic findings.—Large central neuroma evidenced structurally; suture included in the sections. Distal ulnar degenerated.

Experiment No. 281.—Dog No. 56; large dog; full grown; 172 days. July 24, 1918, right ulnar exposed and resected 4 cm. A segment of a formalized carotid artery of a dog slipped over the central ulnar stump, which was freed from bed for sufficient length to admit of this. One through-and-through waxed, silk thread suture passed, and under tension resected nerve ends brought together and suture tied. After tying knot, resected nerve ends found to be 1.5 cm. apart. The formalized arterial tube was then slipped down over the suture and the resected nerve ends; fascia stitched and the wound closed. January 11, 1919, dur-

ing the night, dog hung himself on tie rope; was in good condition. On exposing the right ulnar, arterial tube is found to be well in place; with central and distal ulnar stumps firmly fixed within the arterial tube. Black, tension suture clearly seen through wall of arterial tube. No material increase of connective tissue about arterial tube and nerve observed. Large central ulnar bulb noted; distal ulnar has the appearance of a normal nerve. Foreleg muscles supplied by ulnar not atrophic and good color. Dog had been dead some hours so could not test muscles as to functional return. Central and distal ulnar and arterial tube removed and fixed in ammoniated alcohol for pyridine-silver staining. Good differential silver staining attained.

Microscopic findings.—In longitudinal sections of the central ulnar stump and the arterial tube, vessel wall was found to be well preserved and firmly united to the central ulnar stump. Neuraxes can be traced from the distal end of the ulnar bulb through the arterial tube to the distal ulnar stump. In cross sections of the arterial tube in the interval between the two ulnar stumps, the suture can be clearly made out, as also numerous small nerve bundles separated by connective tissue; much as in a tubular suture without tension suture. In the distal ulnar, numerous new neuraxes are observed in all of the funiculi.

Experiment No. 282.—Dog No. 35; medium size; full grown; 269 days. August 20, 1918, left ulnar exposed; resected 4 cm. One through-and-through waxed, silk thread suture passed, and under tension resected nerve ends brought together to within 8 mm. Suture line wrapped with two layers of alcoholized Cargile membrane. Fascia stitched over the nerve; wound closed. Right foreleg not immobilized. May 16, 1919, killed. Dog in very good condition. On exposing the left ulnar, it is evident that the suture gave way; perhaps soon after the operation; resected nerve ends separated. Central ulnar stump found to end in large bulb, from which some fine nerve bundles could be traced through the connective tissue to the distal ulnar stump; which shows slight bulbous enlargement. No trace of the suture or Cargile membrane could be detected. Foreleg muscles supplied by the ulnar present normal color, though are slightly atrophic. A segment of the central and distal ulnar with intervening connective tissue and fine nerve bundles removed and fixed in ammoniated alcohol for pyridine-silver staining. Differential though faint silver staining attained.

Microscopic findings.—In longitudinal sections of the distal end of the central stump and the fibrous tissue 1 cm. distal thereto, it is observed that the alcoholized Cargile membrane wrapped about the suture line at the time of operation, came to lie one side of the distal end of the central stump when the suture gave way, where it is found embedded in fibrous tissue. In cross sections of the connective tissue field, found between the resected nerve ends, about 1.5 cm. distal to the central stump, the Cargile membrane is again observed, embedded in dense fibrous tissue and to one side there may be seen numerous small intercrossing bundles of nerve fibers which may be traced to the central end of the distal ulnar stump, in which scattered neuraxes are to be found.

Experiment No. 283.—Dog No. 39; medium size; full grown; 275 days. August 14, 1918, left ulnar exposed; resected 4 cm. One through-and-through waxed, silk thread suture passed, and under tension nerve ends approached to within about 1 cm.; suture tied. The suture line wrapped with double layer of alcoholized Cargile membrane. Fascia stitched over nerve; wound closed. Left foreleg not immobilized. May 16, 1919, killed. Dog in good condition. On exposing the left ulnar, it is evident that the suture had given way. The central ulnar stump is found to end in large bulb, from the distal end of which a few small nerve bundles can be traced into the connective tissue for a short distance beyond the bulb, but can not be traced to the distal ulnar stump. No trace of suture or Cargile membrane seen. Distal ulnar presents the appearance of a degenerated nerve. The central bulb and the central end of the distal ulnar stump removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good silver differentiation attained.

Microscopic findings.—In longitudinal sections of the central ulnar bulb and the connective tissue distal thereto, it is to be observed that numerous small nerve funiculi, having very tortuous course, may be observed in the connective tissue and the surrounding adipose tissue. In cross and longitudinal sections of the distal ulnar stump, a few scattered new neuraxes are observed, not evenly distributed through the several funiculi. These become less numerous distalward.

Experiment No. 284.—Dog No. 31; medium size; full grown; 276 days. August 16, 1918, right ulnar exposed and resected 4.7 cm. One through-and-through waxed, silk thread suture passed, and under tension resected nerve ends brought together to within a little less than 2 cm. The resected nerve ends and the suture region wrapped in three layers of alcoholized Cargile membrane. Fascia stitched over nerve; wound closed. Right foreleg not immobilized. May 19, 1919, killed. Dog in very good condition. On exposing the right ulnar, it is evident that the suture had given way. Central ulnar is found to end in a large bulb, from the distal end of which several fine nerve bundles pass distalward in the connective tissue, spreading out fan-shaped over the adjacent muscle. None of these nerve bundles could be traced to the distal ulnar stump, which appears to end free and is only very slightly enlarged. The distal ulnar presents the appearance of a degenerated nerve. Central ulnar bulb and the central end of the distal ulnar stump removed and fixed in ammoniated alcohol for pyridine-silver staining. Differential, but faint silver staining attained.

Microscopic findings.—From the distal end of a large central ulnar bulb, evidenced structurally, numerous small nerve funiculi can be traced into the connective tissue; these having a very tortuous course. Remnants of the alcoholized Cargile membrane, embedded in fibrous tissue, noted. In the distal ulnar stump only a few scattered neuraxes, found mainly in one large funiculus, noted; very few in the several other funiculi observed.

Experiment No. 285.—Dog No. 32; medium size; full grown; 273 days. August 16, 1918, left ulnar exposed; resected 3.4 cm. One through-and-through waxed, silk thread suture passed, and under tension nerve ends approached until they nearly touched; suture tied. Suture line wrapped with two layers of alcoholized Cargile membrane. Oozing in field not fully controlled. Fascia stitched over nerve; wound closed. Foreleg not immobilized. May 16, 1919, killed. Dog in very good condition. On exposing the left ulnar, it is found that the central ulnar stump ends in a long spindle-shaped bulb which leads directly to the distal ulnar stump. It is evident that the suture maintained. Traces of the Cargile membrane made out, though not clearly, since area is surrounded by connective tissue. Distal ulnar presents the appearance of a normal nerve. Foreleg muscles supplied by ulnar present the appearance of normal muscle. Central and distal ulnar segment removed and fixed in ammoniated alcohol for pyridine-silver staining. Good silver differentiation attained.

Microscopic findings.—In longitudinal sections, including the central ulnar bulb, suture line and central end of distal ulnar stump, it can be clearly seen that in this case the tension suture did not give way, since in the sections the sections of the suture thread can clearly be made out and are found in proper position. Distinct evidence is had of the Cargile membrane, wrapped about the suture line at the time of operation. This is found embedded in fibrous issue. Neuraxes coming from the central ulnar stump can be traced directly into the distal ulnar stump, in which they may be traced to the region of muscle innervation. In cross sections of the distal ulnar at the level of the elbow, numerous neuraxes distributed evenly through all of the funiculi, are to be observed. Very complete regeneration of the distal ulnar obtained.

Experiment No. 286.—Dog No. 39; medium size; full grown; 326 days. June 24, 1918, right ulnar exposed; resected 3.2 cm. One through-and-through silk thread suture passed. Under tension the resected nerve ends brought together to within 1 cm.; suture tied. The suture lines wrapped with two layers of Cargile membrane. Fascia stitched over nerve; wound closed. Foreleg not immobilized. May 16, 1919, killed. Dog in very good condition. On exposing the ulnar nerve, it is evident suture had given way; ends of resected ulna; separated. Central ulnar stump found to end in large bulb, from the distal end of which fine nerve bundles may be traced about 2 cm. distal over the adjacent muscle, but do not appear to reach the distal ulnar stump. Distal ulnar presents the appearance of a degenerated nerve. Central ulnar bulb and distal ulnar stump fixed in ammoniated alcohol for pyridine-silver staining. Fairly good silver differentiation attained.

Microscopic findings.—From the distal end of the large central ulnar bulb, numerous small nerve funiculi can be traced distalward in the connective tissue, having very tortuous course. In cross and longitudinal sections of the distal ulnar stump, at successive levels to the elbow, only scattered neuraxes are found and these are not found evenly distributed through the several funiculi. Partial but very incomplete regeneration of the distal ulnar attained.

Experiment No. 287.—Dog No. 2; medium size; full grown; 342 days. June 12, 1918, left ulnar exposed; resected 2.5 cm. One through-and-through silk thread suture passed. Under tension the resected nerve ends brought together until they meet; suture tied. Suture line wrapped with two layers of Cargile membrane. Fascia stitched over the nerve; wound closed. May 20, 1919, killed. Dog in very good condition. On exposing the left ulnar, evident suture had given way; resected ulnar ends found separated. Central ulnar ends in large bulb, from the distal end of which there can be traced several fine nerve bundles which are found to spread out fan-shaped over the adjacent muscle. These fine nerve bundles could not with certainty be traced to the distal ulnar. The distal ulnar presents the appearance of a partially regenerated nerve. On slowly cutting the distal ulnar at the level of the elbow, after exposing the forearm muscles supplied by ulnar, feeble contraction of these muscles is noted. Certain of the central fibers appear to have reached the distal ulnar segment. Central and distal ulnar and intervening connective tissue removed and fixed in ammoniated alcohol for pyridine-silver staining. Fairly good silver differentiation attained.

Microscopic findings.—Very large central ulnar bulb evidenced structurally, from the distal end of which numerous small nerve funiculi, having very tortuous course, can be traced into the connective tissue. No trace of Cargile membrane observed. In cross and longitudinal sections of the distal ulnar there are observed a good number of new neuraxes, fairly evenly distributed through the several funiculi; these are clearly made out in cross sections of the distal ulnar at the level of the elbow. Fairly complete regeneration of the distal ulnar attained.

In 10 of the 13 experiments of tension sutures, it is quite evident that the tension sutures gave way, permitting the nerve ends to separate and to withdraw centrally or distally or both from the tubular sheath applied. This separation of nerve ends apparently occurred within a few days after the operation. The pressure of the suture on the epineural and perineural connective tissue in the line of tension can not help but weaken these fibrous tissue layers and cause them to give way in the direction of the suture pull. Immobilization of the part may lessen the tendency of the tension suture to tear and obviate certain gross strains but can not prevent the direct action of the suture on the fibrous sheaths of the nerve. In the experiments in which the tension suture gave way, the approximation of the nerve ends, made for the purpose of facilitating the down-growing central neuraxes to reach the distal stump was probably lost before the regenerative process was well under way. Of interest are the records of the experiments in which it seemed apparent that the tension sutures had given way, which had been kept for periods varying in the several experiments (No. 282, No. 283, No. 286 and No. 287) from about 9 months to nearly 11 months. In all of these experiments the nerve ends were found separated to nearly the distance recorded at the time the tension suture was applied. In each case there was found a large central bulb and from this there could be traced a variable number of larger and smaller nerve bundles, spread out fan-shaped on the muscle bed or winding their way in tortuous course through the connective tissue. It was not possible to trace these small nerve funiculi to the distal stump, but in sections of the central end of the distal stump neuraxes were found scattered through the funiculi, clearly differentiated in pyridine-silver preparations. These observations show the extent to which down-growing neuraxes will grow in connective tissue. The manner of the downgrowth of these neuraxes confirms the view that the tension sutures gave way within a few days after operation. The downgrowth of neuraxes in connective beds, in intermuscular septa, in the connective tissue between muscle fasciculi and over fascial layers, centimeters

distal to the central nerve bulb, in several of these experiments reaching the distal stump, explains the manner of spontaneous regeneration after nerve severance, a phenomena of not unusual occurrence. The downgrowth of central neuraxes in the manner above indicated needs to be considered in judging by the mere "return of function" in experimental and in clinical work the worth of operative procedures used for bridging nerve defects; the down-growing neuraxes in the experiment or in the clinical case in question may have reached the distal stump in spite of the operative procedure. A careful control, based on a study of serial sections stained by methods giving differential neuraxis staining is necessary before the results of a particular method of peripheral nerve repair can be evaluated.

In three of the experiments the tension sutures maintained. In Experiment No. 277, the left ulnar nerve was resected only 2.5 cm. With a single suture the nerve ends were brought together to within 2 mm. On exposing the ulnar 54 days after the operation the nerve ends were found in approximately the same relative position. A relatively small number of new neuraxes were found in the central end of the distal stump having passed the connective tissue layer intervening between the nerve ends. In Experiment No. 281, examined somewhat over five months after the operation, the right ulnar had been resected 4 cm. By tension suture the ends were brought together, but on tying had again separated to the extent of 15 mm. In this case a formalized arterial tube had been slipped over the suture region, the experiment was thus to some extent a tubular suture. At the time the ulnar was exposed the suture in place could be seen through the wall of the tubular sutures also found well in place. This dog had accidentally hung himself on the tie rope; the nerve could thus not be tested functionally. In pyridine-silver preparation numerous new neuraxes were found in the distal ulnar which could be traced to the central nerve bulb, through the arterial tube. It is clear that in this experiment the tension suture maintained and that the tubular suture prevented dispersion of the down-growing neuraxes. The neurotization of the distal ulnar was quite complete. In Experiment No. 285, examined approximately nine months after the operation, the left ulnar was resected to the extent of 3.4 cm. and under tension suture the nerve ends were approached until they nearly touched; two layers of alcoholized Cargile membrane were wrapped about the suture line. On exposing the ulnar a long spindle-shaped central nerve-bulb was found to lead directly to the distal ulnar segment. In sections, the suture was found in place. Numerous neuraxes derived from the central stump and found distributed quite evenly through the several funiculi of the distal ulnar segment could be traced to the level of the elbow. These three experiments indicate that should a tension suture maintain, regeneration from the central stump is in no way inhibited by the tension to which the nerve ends are subjected. It is evident from the study of microscopic sections that the tubular sheaths employed facilitate materially the down growth of the central neuraxes.

Tension sutures, wrapped with alcoholized Cargile membrane or formalized arterial tube, while in a measure successful in a limited number of experiments of this series, are not to be recommended in preference to other methods of bridging nerve defects, notably nerve transplantation, which offers greater assurance of success.

GENERAL CONCLUSIONS

1. The experimental observations here presented, controlled for the great majority of the experiments through microscopic study of either the entire operated nerve or so much thereof as was deemed advantageous, treated en bloc by the pyridine-silver method, cut and mounted serially and stained with special reference to neuraxis differentiation, when considered collectively, present convincing evidence in support of the monogenetic view of the regeneration of peripheral nerves degenerated as a consequence of mechanical or chemical injury. According to this view, regeneration of the distal, degenerated segment of a peripheral nerve is through downgrowth of neuraxes sprouts or buds derived from the undegenerated neuraxes of the central stump. The series of experiments on nerve transplantation, and more particularly such in which homogenous nerve segments were used to bridge nerve defects, appear to us to warrant the deduction that the sine qua non of peripheral nerve regeneration is the downgrowth of central neuraxes, since the sheath cells of the transplanted nerve fibers presented no evidence of latent vitality as manifested by proliferation and appeared to be without biological significance so far as growth of neuraxes through the transplanted nerve fiber is concerned. That down-growing neuraxes may grow relatively long distances in the absence of sheath cells derived from either the central or distal stump of a divided nerve seems to be established by these experimental observations, the experiments confirming deductions drawn from observations on tissue culture and experimental embryological studies (Harrison) to the effect that sheath cells are not essential to the growth of the neuraxes. The ultimate relation of sheath cells to the budding and growing neuraxes and the ultimate relation of the down-growing neuraxes to the syncytial protoplasmic bands (Büngner's "bandfasern"), the end product of Wallerian degeneration of peripheral nerve fibers, has not been conclusively determined. The pyridine-silver methods in common with other silver precipitation methods of neuraxis staining, while permitting excellent neuraxis differentiation, are not methods which would be selected for the study of finer cytologic details. Other methods of histologic study were not given consideration. The reason for this series of experimental studies on peripheral nerve repair did not warrant extended duplication of experiments and of necessity influenced the special fields of inquiry. Our observations answer only in a very general way and not decisively the question of the intraprotoplasmic or the extraprotoplasmic position of the new neuraxes. The end-discs found in our preparations, so far as can be determined, present the same form and structure as those found on the end of nerve fibers growing in tissue culture (Harrison) and are of a diameter which is several times greater than the diameter of the protoplasmic syncytial bands. A decisive answer to the question of the relation of the down-growing neuraxes and the syncytial protoplasmic bands of degenerated peripheral nerves is perhaps not to be

found as a result of study of sections, but rather to be sought in experimental observations on the regeneration of nerve fibers devoid of sheath cells.

2. These experimental observations warrant the conclusion that bridging a nerve defect by means of a nerve transplant is a legitimate operation and that on the whole the most satisfactory results are to be obtained by use of autogenous-nerve transplants. For purpose of clinical surgery a multiple or cable auto-nerve transplant is recommended, using several segments of one or of more than one cutaneous nerve, which may be sacrificed without material loss of function. The question of the particular cutaneous sensory nerve to be selected for purpose of nerve bridge is not material and depends largely on the convenience of the operators; the question of the funicular arrangement of the nerve selected is of quite secondary importance; whether the central or distal end of the nerve segment to be transplanted is placed centralward it is not necessary to consider. The sum total of the nerve segments transplanted should approximate in cross diameter that of the nerve bridged; experimental evidences at hand showing clearly the value of accurate end-to-end approximation of the cut surfaces in placing a nerve bridge. The suture material found experimentally to be the most serviceable is a fine, waxed silk thread, threaded on fine round and half-curved needles, which are passed through the nerve and transplant and adjusted so as to obtain accurate apposition of the cut surfaces of the nerve ends. In many of the experiments in which sutures were placed, the suture line and the adjacent nerve segments were cut longitudinally into serial sections. It is surprising to note the slight evidence of connective tissue reaction, even in experiments examined a long time after the operation. The down-growing neuraxes derived from the central stump, penetrate the transplant through the central wound and course distally within the funiculi of the transplanted nerve segments and to a large extent within the neurolemma sheaths of the transplanted nerve fibers. Such down-growing neuraxes as reach the distal wound pass through this and penetrate the distal segment of the nerve. A histologic study of material obtained from numerous experiments on bridging nerve defects with nerve transplants, even when made from autogenous tissue, convinces that the function of the nerve transplant is to large extent merely mechanical, in that it offers numerous microscopic tubular structures, which maintain for a relatively long period and serve for the downgrowth of central neuraxes. Even in autogenous peripheral nerve tissue when used as a nerve bridge the sheath cells of the transplanted nerve fibers are without biological significance. The value of a nerve transplant is proportionate to the extent in which the neurolemma sheaths are patent relatively early after transplantation, and it is a question whether the superiority of autogenous and homogenous transplants as against heterogenous-nerve transplants is not to be ascribed to the relative potency of the neurolemma sheaths relatively early after transplantation rather than to other ascribed causes. The funicular pattern of the central segment of a bridged nerve is to a large extent lost as the downgrowing neuraxes pass through the central wound. The neuraxes reaching the distal end of the transplant meet with further rearrangement on passing through the distal wound. Thus there is no possibility of maintaining the funicular pattern of a given nerve regenerated through a nerve transplant. In so far as

has been determined experimentally, there is no reason to assume that the downgrowing neuraxes manifest any selectivity on reaching the peripheral segment after bridging (or after a primary or secondary nerve suture). The neuraxes derived from efferent neurones no doubt enter the neurolemma sheaths found in the distal segment of both efferent and afferent peripheral nerve fibers and vice versa. It is assumed that chance brings at least as many branches to homologous nerve fibers as to heterogenous nerve fibers. A very great increase in the number of new neuraxes found in the peripheral end of the central stump permits many new nerve-fiber branches to go astray in the scar tissue, the transplant, and in the peripheral stump and still leave a sufficient number to admit of structural and functional regeneration.

3. Experimental observation warrants the conclusion that the placing of a homogenous-nerve transplant is an operation which is justified. This operative procedure is made more available to clinical surgery through the convincing experimental results obtained with stored homogenous nerve transplants, and especially with nerve transplants stored in sterile liquid petrolatum. The downgrowth of central neuraxes through the funiculi and the neurolemma sheaths of nerve fibers of homogenous-nerve transplants stored in liquid petrolatum is quite as rapid and very nearly as good as when fresh auto-nerve transplants were used. The possibility of thus storing peripheral nerve tissue when opportunity presents itself makes the operation of homogenous-nerve transplantation to bridge nerve defects more available as a surgical procedure. This operation obviates the necessity of making a second wound, as is generally necessary when it is desired to obtain autogenous nerve tissue. The method of making a multiple or cable-homogenous-nerve transplant, of using a number of smaller nerve bundles rather than one large nerve, is here suggested; this has not been tested experimentally but commends itself when considered in the light of observations on cable-auto-nerve transplants. The use of homogenous nerve tissue, stored in 50 per cent alcohol for the purpose of nerve bridge, deserves serious consideration. The experimental results obtained are encouraging. The simplicity of this method of storage commends itself.

4. The experimental evidence presented with reference to heterogenous-nerve transplants confirms the earlier observations of Huber that regeneration of a severed nerve with loss of substance may take place through a heterogenous-nerve transplant. So far as can be judged on gross inspection and on study of histologic sections, the source of a nerve transplant does not materially influence the fibrous union of the respective end of the nerve transplant and the resected nerve. If a satisfactory suture is made with desired end-to-end approximation of the cut surfaces the fibroblastic reaction appears essentially the same whether auto-, homo-, or heterogenous nerve segments are used to bridge the nerve defects, suggesting the conclusion that histogenetically the fibrous tissue of the wound regions is derived primarily from the parent nerve and not from the connective tissue elements of the nerve transplant. The source of the nerve transplant does not per se appear to influence the extent of connective tissue proliferation in the field surrounding the nerve transplant. On gross inspection the heterogenous-nerve transplant appears to serve the

purpose of a nerve bridge quite as satisfactorily as an autogenous- or homogenous-nerve transplant. However, on study of an extended series of microscopic sections of tissue, removed in experiments in which heterogenous-nerve transplants were made, differentially stained for determination of neuraxes, the conviction grows that while a certain relatively small per cent of down-growing central neuraxes may pass through the neurolemma sheaths of the nerve fibers found within the funiculi of the transplanted nerve segment, a much larger per cent of down-growing neuraxes are found in the connective tissue sheaths of the nerve transplant and in the immediately surrounding connective tissue. Many of these extrafunicular down-growing neuraxes, found in the connective tissue either as single fibers or as small bundles of fibers, reach the region of the distal wound and through it bring about neurotization of the distal segment of the nerve. So far as may be determined from a study of pyridine-silver stained preparations of the extensive series of experimental observations on nerve transplantation, the fragmentation of the neuraxes and the myelin, their dissolution, and removal in the transplanted nerves no matter whether auto-, homo-, or heterogenous nerve tissue is considered, is not the same as in the process of Wallerian degeneration as found concurrent in the distal segment. The participation of the sheath cells of the transplanted nerve fibers in the fragmentation and removal of the neuraxes and myelin has not been established and seems quite secondary. The conclusion seems warranted that neither in auto-, homo-, nor in hetrogenous nerve transplants are the sheath cells of the transplant of biological significance in the regeneration of the nerve. The much more favorable results obtained experimentally on use of autogenous and homogenous transplants, even when the latter have been stored for extended periods before use, than when heterogenous-nerve tissue is used, can not be attributed to the behavior of the sheath cells in the respective experiment, since this difference extends to heterogenous-nerve transplants stored in alcohol. The experimental evidence presented argues for the elimination of the use of heterogenous-nerve transplants as a surgical procedure.

5. When sheathing of a nerve is deemed necessary after neurolysis, nerve suture or nerve transplantation or other operative procedure on peripheral nerves, the use of alcoholized Cargile membrane in double or triple layers deserves consideration as a surgical procedure. Experimental observations indicate that it remains in the tissue 5 to 6 months without absorption and in healthy tissue and aseptic wounds without causing fibrous tissue proliferation. Alcoholized Cargile membrane is readily prepared, is easily applied, and is pliable when bathed in the tissue juices. There was no opportunity for testing experimentally the behavior of alcoholized Cargile membrane in the presence of scar tissue. The several series of experimental observations in which various substances were used for ensheathing operated nerves permit the conclusion that alcoholized Cargile membrane used for the purpose of a tubular sheath in peripheral nerve repair is to be given preference over tubular sheaths prepared from formalized arterial tubes, auto-fascial sheaths prepared from fascia lata, and a fat sheath or fat membrane; it is more readily prepared and applied and incites less connective tissue proliferation. Cargile membrane as generally available is useless for this purpose by reason of its early absorption.

6. Experimental evidence is at hand to substantiate the view that regeneration of a severed nerve with loss of substance can take place through a tubular suture. The experiments in which downgrowth of central neuraxes through the lumen of a tubular suture was obtained offer convincing evidence in support of the monogenetic view of peripheral nerve regeneration. The experiments of tubular suture in the repair of severed nerves with loss of substance are of academic interest. While regeneration through a tubular suture is possible, this method of operative procedure does not commend itself in surgical practice, since it is less certain of favorable results than when auto- or homo- nerve transplants are used.

7. Experimental observations contraindicate the application of tension sutures in the repair of severed peripheral nerves.

8. Amputation neuromata form at the distal end of the central stump in aseptic wounds relatively early after nerve severance, and are regarded as a thwarted attempt at nerve regeneration. The injection of absolute alcohol into the nerve about 2.5 cm. above the place of section in experimental observations prevents neuroma formation.

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